GUIDELINES
FOR
DESIGN AND INSTALLATION OF
GABION STRUCTURES

INDIAN ROADS CONGRESS
2018

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GUIDELINES FOR DESIGN AND INSTALLATION OF GABION STRUCTURES

BACKGROUND

Gabion structures are being practiced in India for more than 30 years. Internationally, these type of structures have history of more than a century. The use is increasing day by day on account of its inherent advantages over conventional earth retaining structure. However, there was no IRC document which gives guidelines on design, and installation of gabion structures. The IRC Committee B-3 felt the need for such a document, which will be useful to the practicing engineers in the field of highway and bridge structures. The B-3 Committee constituted a sub-committee comprising of the following to draft the document.

Shri Sharad Mahiaiskar	....	Convenor
Shri PL Bongirwar	....	Member
Dr N.V. Nayak	....	Member
Shri S. Ray	....	Member
Shri RK Jaigopal	....	Member
Shri Dilip Karamdhikar	....	Member
Dr. Ratnakar Mahajan	....	Member
Shri Sarokh Bagli	....	Member

The sub-committee deliberated extensively and draft was presented before the B-3 Committee several times. The committee finalized the draft "Guidelines for Design and Installation of Gabion Structure" during its meeting held on 09.09.2017 for placing before the BSS Committee.

The draft was considered by the Bridges Specifications and Standards Committee (BSS) in its meeting held on 23.10.2017 and approved the document. The document as approved from BSS Committee was placed before the IRC Council in its 213th meeting held on 03.11.2017 at Bengaluru (Karnataka). The Council approved the document.

The Foundation, Sub-Structure Protective Works and Masonry Structures Committee (B-3) of the Indian Roads Congress was constituted in 2015 with the following personnel:

Sharma, R.S.	....	Convenor
Arora , Daljeet Singh	....	Co-Convenor
Jain, Sanjay Kumar	....	Member Secretary

Members

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Joglekar, S G	Rana, Dr. Sanjay
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1 INTRODUCTION

A Gabion structure is prepared from pre-assembled rectangular cages made of double twisted steel woven wire mesh filled with rocks/ boulders. It is a simple gravity retaining structure, which retains soil with its weight. These types of structures are in use in highways, bridges, canal linings, buildings, shore protection works, etc., as shown in **Fig. 1a to d**. The porosity of gabions prevents the pore-water pressure development behind the walls which, is one of the major advantages of these kinds of systems. These structures blend with the surroundings and allow vegetation to take roots through the structure which enhances the life of the structure. Reduced carbon foot prints are also a noticeable feature when compared to conventional solutions.

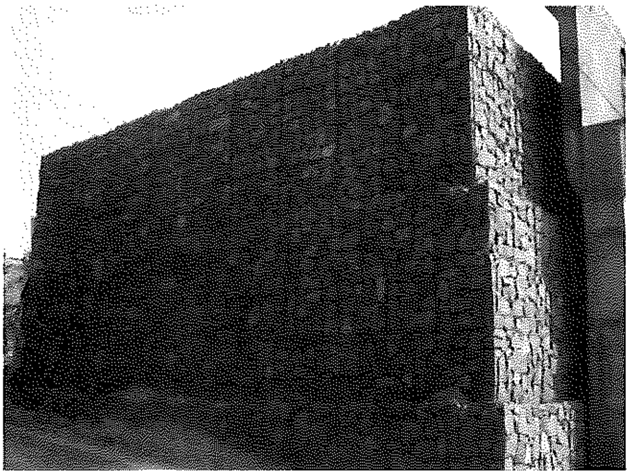


Fig. 1a Soil Retaining behind an Abutment

Fig. 1b Apron Works

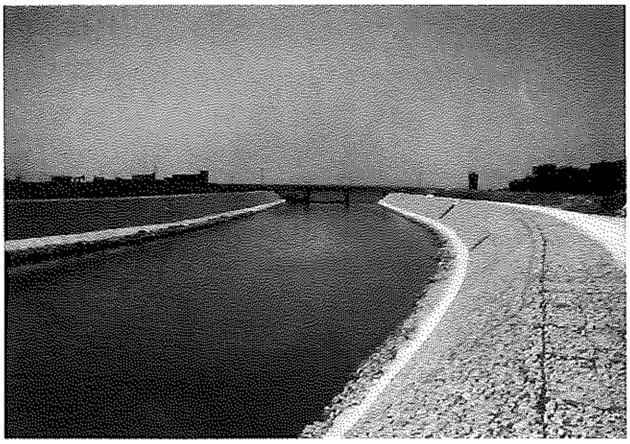


Fig. 1c Shore / Bank Protection

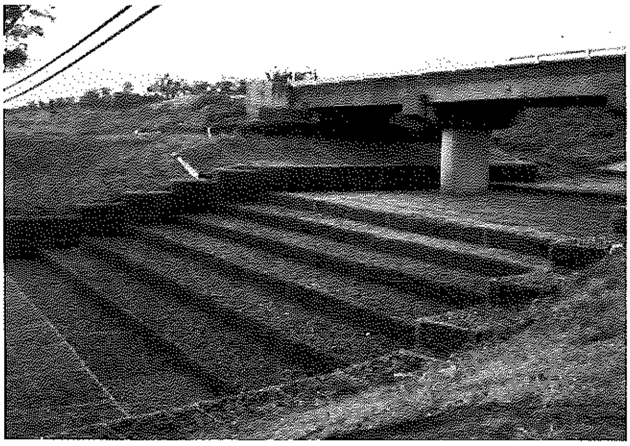


Fig. 1d Bridge Abutment Protection

2 SCOPE

These guidelines cover the specifications, design principles and installation methodology for Gabion and Revet Matresses for use in highway and bridge structures.

3 ELEMENTS OF GABION

Following sections describe the characteristics of the materials used in construction of gabion walls. In addition to the gabion elements, the performance of the gabion structure hinges on the properties of infill, retained fill and the rockfill and other components and measures for efficient design and adoptability.

3.1 Mechanically Woven, Double-Twisted Hexagonal Wire Mesh Gabions

Gabion is rectangular box made from mechanically woven double twisted hexagonal mesh filled with rock or stones **(Fig. 2c)**. A terminal wire is used to edge the wire mesh perpendicular to the double twist by mechanically wrapping the mesh wires around it at least 2.5 times **(Fig. 2a)**.The hexagonal shape of the mesh helps in achieving uniform distribution of forces. Mesh should be non-corrosive and should possess high tensile strength. The details of the different mesh types, sizes and various tests are available in IS 16014 and are reproduced in and **Table 3**. The wires of the mesh should be galvanised with zinc and/or polymeric (coating like Polyvinyl Chloride (PVC), Polyamide (PA6), other polymer etc.) coated to prevent corrosion. Better coatings of Zn Al alloy like Zn 95% Al 5% and Zn90% Al 10% are used which are better than only Zinc. Similarly better polymeric coatings like polyamide are used.

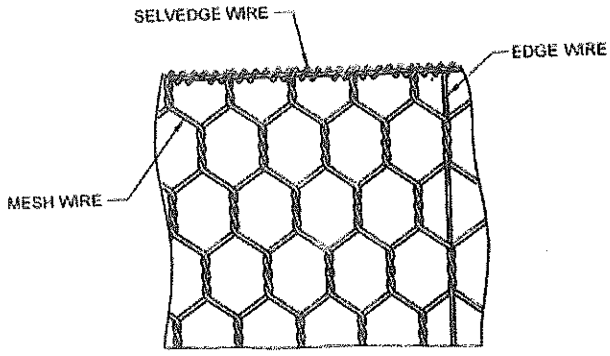


Fig. 2a Details of Mesh Wire, Selvedge and Edge Wire

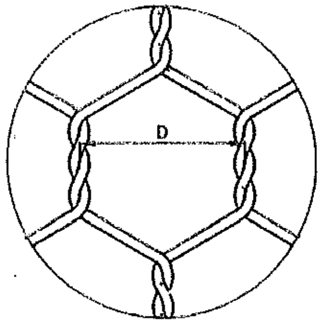


Fig. 2b: Mesh Type and Nominal Size (D)

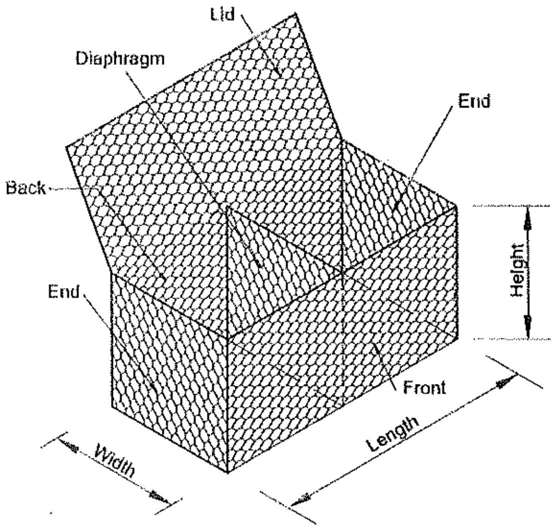


Fig. 2c: Details of Assembled Gabion Box

Gabion boxes are generally transported in collapsed condition and are restructured into boxes of required dimensions at the site. These boxes are joined using stainless steel fasteners or lacing wires or galvanised rings depending on the specifications. All these materials should be tested and confirmed to the specifications as per IS 4826, IS 12753, IS 4454 (IV). The tensile strength of mesh wire lacing wires, stiffeners and fasteners should be in accordance with the specifications and requirements as directed by IS 280, with minimum elongation of 10 percent with the test performed on a gauge length of test specimen of 200 mm. Minimum tensile strength of the wire mesh and zinc and polymeric coating shall be as per **Table 5**. **Table 14** gives the requirements of wire coating according to the environmental conditions.

3.2 Polymeric Gabions

Polymeric gabions **(Fig. 3)** and revet mattresses can be made using polymeric materials such as polymeric rope or geogrids. These materials can be easily used in saline waters also. However, such type of gabions may not be able to retain the intended shape as effectively as compared to steel wire gabions. Polymeric materials starts degrading once

exposed to sunlight. Also, polymeric materials are highly flammable and catch fire easily. Hence, such gabions are mainly used in underwater application or application where these materials are not exposed to direct sunlight. Proper machinery shall be considered for lifting of ropes while installing polymeric gabions underwater, so that the ropes are not damaged in this process.

Fig. 3: Polymer Rope Gabions

3.3 Revet Mattress

Revet mattress **(Fig. 4)** is a wire mesh container uniformly partitioned into internal cells with relatively smaller height in relation to other dimensions, having smaller mesh openings than the mesh used for gabions. It is specialized form of Gabion and has relatively larger plan size and shallower depth **(Table 4)**. Their primary function is to protect the bed of watercourse from excessive scour. It is intended to prevent the water ripping up its own bed, most commonly at weirs, waterfalls and other places where there is a sudden change in water level. Revet mattresses are generally used for riverbank protection and channel linings. Minimum tensile strength of the wire mesh and zinc and Polymeric coating shall be as per **Table 5**.

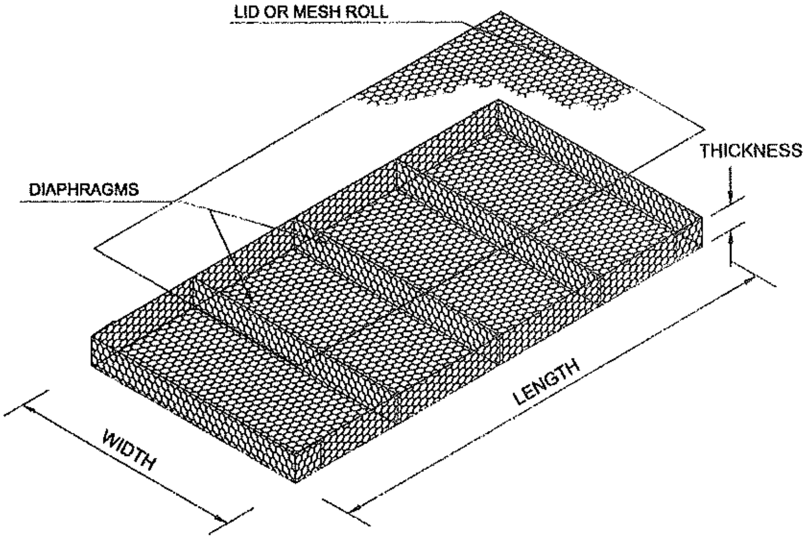


Fig. 4: Details of Assembled Revet Mattress

3.4 Prefilled Gabions / Revet Mattress

Gabions are filled on site manually or with machinery. In case of underwater application, gabion filling is not possible. Also, in case of emergency filling of gabion is not feasible. In such conditions gabions are prefilled and installed. Generally, gabions for prefilled application are filled in the plant or suitable nearby location.

4 COMPONENTS OF GABION RETAINING WALL

Gabion walls are mass gravity walls having three major components like gabion box, stone for filling gabion, filter media and backfill (Fig. 5). This section presents specifications of various materials used in gabion structures.

- Technical Specification of Gabion / revet Mattress Mesh
- Rocks for filling the Gabion
- Filter media
- Foundation and Backfill soil properties

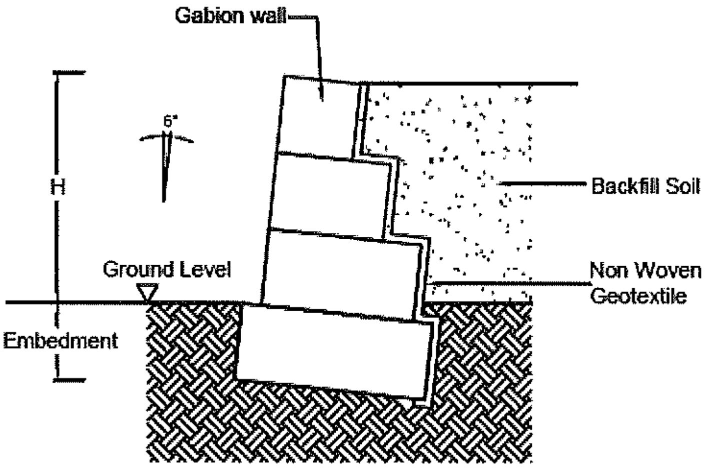


Fig. 5: Typical Section of Gabion Wall with Different Component

4.1 Technical Specification of Gabion / Revet Mattress Mesh

a) Wire technical specification used in Gabion / revet Mattress mesh

All tests on the mesh, lacing wire and selvedge wire **(Fig. 2a)** must be performed prior to manufacturing the mesh.

Tensile strength: The wire used for the manufacture of Mesh shall have a tensile strength minimum 350 N/mm2 – 550 N/mm2 in accordance with IS 280. Wire tolerances shall be in accordance with IS 16014 (Class T1).

Elongation: Elongation of wire shall not be less than 10%. Test must be carried out on a sample at least 20 cm long.

Metallic coating: The wire shall have minimum quantities of metallic coating given in accordance with IS 4826 and Zn Al alloy coating has been given as per **Table 1**.

Ageing and corrosion resistance

1. Zinc metallic coating- When subjected to test in a sulphur dioxide environment according to the procedures in ISO 6988 (0,2 dm³ SO2 per 2 dm³ water) after 14 cycles of discontinuous test, the mesh samples surface shall not show more than 5 % of DBR (Dark Brown Rust).

   When subjected to the neutral salt spray test according to the procedures in ISO 9227 after a period of 500 h of exposure, the mesh sample surface shall not show more than 5 % of DBR.

2. 95% Zn+ 5%Al - When subjected to test in sulphur dioxide environment according to procedures in ISO 6988 after 28 cycles of discontinuous test, the test samples shall not show more than 5% of DBR (Dark Brown Rust).

   When subjected to the neutral salt spray test according to the procedures in ISO 9227 after a period of 1000 hr of exposure, the mesh samples shall not show more than 5 % of DBR.

3. 90% Zn+ 10%Al - When subjected to test in sulphur dioxide environment according to procedures in ISO 6988 after 56 cycles of discontinuous test, the test samples shall not show more than 5% of DBR (Dark Brown Rust).

   When subjected to the neutral salt spray test according to the procedures in ISO 9227 after a period of 2000 hr of exposure, the mesh samples shall not show more than 5 % of DBR.

   Adhesion of metallic coating: The adhesion of the zinc coating to the wire shall be such that, when the wire is wrapped six turns around a mandrel having four times the diameter of the wire, it does not flake or crack when rubbing it with the bare fingers in accordance with EN 10244-1 and IS 4826.

Table 1 Minimum Mass of Metallic Coating for Heavily Coated, Soft Type for Different Wire Sizes Used in Gabion and revet Mattresses[4]

Sr. No	Nominal Diameter of Galvanized Wire mm	Mass of Zinc/Zinc Alloy coating g/m^2	Permitted Tolerances on wire diameters mm
1	2.00	240	±0.05
2	2.20	240	±0.06
3	2.40	260	±0.06
4	2.70	260	±0.07
5	3.00	270	±0.08
6	3.40	270	±0.09
7	3.90	280	±0.10

b) Internal Connecting Wires

Cross Ties/ stiffener wire: Galvanized wire diameter 2.2 mm, and with Polymeric coating, 3.2 mm when measured with Polymeric coating.

c) PVC (Polyvinyl Chloride) Coating

- Specific gravity — in the range from 1.30 to 1.35 when tested in accordance with IS 13360(Part 3) / ISO 1183.
- Tensile strength — Not less than 20.6 MPa when tested in accordance with IS 13360 (Part 5) /ISO 527. Elongation at break: not less than 200% in accordance with ISO 527.
- Hardness — Shore 'D' between 50 and 60,when tested in accordance with IS 13360 (Part 5) / ISO 868.
- Resistance of PVC coating to sodium chloride solution — When PVC coated wire is tested in accordance with IS 16014 ,there shall be no loss of mass.
- Salt spray exposure — The PVC shall show no effect after 3000 h of salt spray exposure in accordance with IS 13360 (Part 8)/ ISO 9227
- Coating thickness – Nominal 0.5 mm and minimum 0.4 mm

d) **Mesh opening:** Mechanically woven wire mesh has mesh opening as show in **Fig. 2b**. Mesh opening for different mesh type is shown in **Table 2**.

Table 2 Mesh Opening Size

Mesh Type	'D' Mesh Opening Nominal Size (mm)	Tolerance (%)
6x8	60	0 to + 8
8x10	80	0 to +12
10x12	100	- 4 to +12

Table 3 Technical Specification of Gabion [4]

Sr. No.	Characteristics	Mesh Type					
		10x12			8x10		
		Only Zn / Zn Al alloy		Zn / Zn Al alloy + Polymer coated	Only Zn / Zn Al alloy		Zn / Zn Al alloy + Polymer coated
1	Mesh wire dia,mm	2.70	3.00	2.70/3.70 (ID/OD)*	2.70	3.00	2.7/3.7(ID/OD)*
2	Edge/Selvedge wire dia,mm	3.40	3.90	3.40/4.40(ID/OD)*	3.40	3.90	3.40/4.40(ID/OD)*
3	Lacing wire dia,mm	2.20	2.20	2.20/3.20(ID/OD)*	2.20	2.20	2.20/3.20(ID/OD)*
4	Polymeric coating thickness, mm	NA		Nominal-0.50, Minimum-0.40			Nominal-0.50, Minimum-0.40
5	Typical sizes-Length x Width x Height (in meter) (Number of diaphragms)	4x1x1(3 Nos), 3x1x1(2 Nos), 2x1x1(1Nos), 1.5x1x1(0 Nos), 2x1x0.5(1 Nos), 3x1x0.5(2 Nos), 4x1x0.5(3 Nos), 2x1x0.3(1 Nos), 3x1x0.3(2 Nos), 4x1x0.3(3 Nos)					
6	Tolerance in size of gabion box	Length and Width ±5 percent; Height >0.3 m ±5 percent; Height≤0.3m ±10 percent;					

* ID/OD - Internal diameter/Outer diameter of Polymer coated/wire

Table 4: Technical Specification of Revet Mattresses [4]

Sr. No.	Characteristics	Mesh Type	
		6x8	
		Only Zn / Zn Al alloy	Zn / Zn Al alloy + Poly coated
1	Mesh wire dia, mm	2.20	2.20/3.20 (ID/OD)*
2	Edge/Selvedge wire dia, mm	2.70	2.70/3.70(ID/OD)*
3	Lacing wire dia,mm	2.20	2.20/3.20(ID/OD)*
4	Polymeric coating thickness, mm	NA	Nominal-0.50, Minimum-0.40
5	Typical sizes-Length x Width x Height (in meter) (Number of diaphragms)	4x2x0.17(3Nos), 3x2x0.17(2 Nos), 2x2x0.17(1 No), 4x2x0.23(3 Nos), 3x2x0.23(2 Nos), 2x2x0.23(1Nos), 4x2x0.30(3 Nos), 3x2x0.30(2 Nos), 2x2x0.30(1 No)	
6	Tolerance in size of gabion box	Length and Width..±5 percent; Height≤0.3 m.....±10 percent	

* ID/OD - Internal diameter/Outer diameter of Polymer coated wire

e) Tests and Standard of Acceptance

Gabion and revert mattress mesh and materials shall be tested in accordance with procedure outline below and IS 16014 and shall meet prescribed criteria mentioned in **Table 5**.

Tensile Strength of Wire Mesh Panel

The wire mesh specimens shall be representative of proper field construction as to materials, mesh geometry, and workmanship, and shall be as large as practical to minimize the effect of variations. The tests shall be run with the load applied parallel to the axis of the twist and repeated on a separate test specimen with the load applied perpendicular to the axis of the twist.

Place the mesh into the machine grips such that the gripped mesh will be maintained in the mesh geometry characteristic of field use. The specimen of approximately 0.8 m width and 0.5 m height shall be tested. The effective width to be considered for test specimen shall be the distance between two extreme gripping points. The specimen should extend by at least one mesh repetition beyond the extreme gripping points on either side. However, specimen should not extend more than two mesh repetitions beyond extreme gripping points. The mesh shall be pre-loaded to 10% of the specified minimum strength and machine head travel stopped. The mesh gauge dimensions shall be recorded at this time and taken as the initial dimensions of the specimen where such dimensions are required. If the sample slips at any of the gripping point during the test, such a test shall be discarded and a new sample shall be taken. The loading shall then continue uniformly maintaining the displacement rate of 75 to 100 mm per minute, until first fracture or unwrapping of an individual wire in the system occurs. The distortion of the mesh or changes in gauge length shall be measured to accuracy consistent with reporting the percentage elongation to the nearest 0.5%.

Punch Test

The punch test could be done using two different apparatus.

1) Pre-Tensioned Punch Test

An uncut section of 1.82 m in length (unselvedged) and not less than 0.91 m in width shall have the ends securely clamped for 0.91 m along the width of the sample. When the width of the section under test exceeds 0.91 m, the clamps shall be cantered along the width and the excess width will be allowed to fall free on each side of the clamped section. The sample shall then be subjected to tension sufficient to cause 10% elongation of the sample section between the clamps. After elongation and while clamped as described above (and otherwise unsupported), the section shall be subjected to a load over 960 cm2 of area applied to the approximate center of the sample section between the clamps and in a direction perpendicular to the direction of the tension force.

2) Secured Punch Test

An uncut section of 1.24 m in length and not less than 0.9 m in width (selvedged), including all selvedge bindings, shall have the sides and the ends securely clamped at every mesh opening to a rigid frame. After being secured as described above, the section shall be subjected to a load over 960 cm^2 applied to the approximate center of the sample section between the clamps and in a direction perpendicular to the direction of the tension force.

The sample shall withstand, without rupture of any strand or opening of any mesh fastening, an actual load applied by means of a circular ram at a uniform rate not to exceed 220 N/s equalling or exceeding the values shown in **Table 5**. The ram head used in the test shall be circular with a 350 mm diameter and have its edges bevelled or rounded to prevent cutting of the wire strands.

Pull-Apart Resistance Test

A set of two identical rectangular gabion panels, each with a width about 10½ mesh openings along a selvedge wire, shall be joined by properly installed wire fasteners along the two selvedge wires so that each fastener confines two selvedge and two mesh wires. If the fasteners are also to be used to join two individual empty gabion baskets, two additional selvedge wires that are each mechanically wrapped with mesh wires shall be included so that each fastener confines four selvedge and four mesh wires. The set of the jointed panels shall be subject to pull-apart resistance test. The specimen shall be mounted on a loading machine with grips or clamps such that the panels are uniformly secured along the full width. The grips or clamps shall be designed to only transmit tension forces. The load will then be applied at a uniform rate not to exceed 220 N/s until failure occurs. The failure is defined as when the maximum load is reached and a drop of strength is observed with subsequent loading or alternately the opening between any two closest selvedge wires, applicable to a fastener confining either two or four selvedge wires, becomes greater than 50 mm at any place along the panel width. The strength requirements of the jointed panels at failure shall be as shown in **Table 5**.

Table 5 Minimum Strength Requirements of Mesh and Connections

Mesh Type	10x12			8x10		6x8	
Characteristics	**Only Zn / Zn Al alloy**		**Zn / Zn Al alloy + Poly coated**	**Only Zn / Zn Al alloy**	**Zn / Zn Al alloy + Poly coated**	**Only Zn / Zn Al alloy**	**Zn / Zn Al alloy + Poly coated**
Wire Mesh Dia (mm)	2.7	3.0	2.7	3.0	2.7	2.2	2.2
Tensile strength parallel to twist (kN/m)	32.0	40.0	32.0	51.1	42.3	33.6	33.6
Tensile strength perpendicular to twist (kN/m)	15.4	20.5	15.4	26.3	20.4	13.1	13.1
Connection to selvedges (kN/m)	10.2	11.22	10.2	20.4	16.32	10.2	10.2
Panel to panel connection using lacing wire or fasteners (kN/m)	10.2	11.22	10.2	20.4	16.32	10.2	10.2
Punch strength (kN)	17.8	19.58	17.8	26.7	21.36	17.8	17.8

f) Fabrication

Gabions shall be manufactured with all components mechanically connected at the production facility. The front, base, back and lid of the gabions shall be woven into a single unit. The ends and diaphragm(s) shall be factory connected to the base. The lid may be a separate piece made of the same type mesh as the basket. All perimeter edges of the mesh forming the basket and top, or lid, shall be mechanically selvedge with wire having a larger diameter.

Gabion is divided into cells by means of diaphragms positioned at approximately 1m centres. The diaphragms shall be secured in position to the base so that no additional lacing is necessary at the jobsite.

4.2 Rocks for Filling the Gabion

An unweathered (sound) naturally occurring angular or crushed hard rock material can be used for filling. Stone for the Gabion facia shall be hard, angular to round, durable and of such quality that they shall not disintegrate on exposure to water or weathering during the life of the structure. The minimum size of the rock to be filled in the boxes is governed by the mesh opening "D" in the mesh as shown in **Fig. 2b**. The minimum and maximum size of the stone used for filling shall be 1.5 to 2.5 times the mesh opening. Each range of sizes may allow for a variation of 5% oversize rock by number of particles, or 5% undersize rock by number of particles, or both. The rock pieces should be properly hand-placed and packed with their larger dimensions in the horizontal position.The size of any oversize rock shall allow for the placement of minimum of three layers of rock must be achieved when filling the 1 m high units and a minimum of two layers for the 0.50 m high gabion units and 0.3m thick gabion mattress.

Table 6 Properties of Rock to be fill in Gabion

Sr No.	Properties of Rockfill	Values
1	Minimum and Maximum size of stone	1.5 to 2.5 times mesh opening
2	Tolerance on size of stone	± 5%.
3	Minimum density	$22 kN/m^3$
4	Los Angeles abrasion value	Not more than 45

Minimum density and Los Angeles abrasion can be changed by designer based on availability of the rock in the area. In places where stones are not available alternate material having good characteristics can be used.

4.3 Filter Media

Filter media shall be nonwoven needle punched or thermally bonded geotextile. The geotextile shall be made of Polyester or Polypropylene. The mean values of geotextile specification shall be as per **Table 7, 8, 10** and **11**.

Table 7 Minimum Geotextile Strength of Geotextile in Terms of MARV under different Installation

Installation condition	Type	Strength property requirements(MARV)							
		Grab strength in Newton(N)as per ASTM D 4632/IS 13162 Part 5		Tear Strength in Newton (N) as per ASTM D 4533/IS 14293		Puncture Strength in Newton (N)as per IS 13162 Part 4		Burst Strength in Newton (N) as per ASTM D 3786/IS 1966	
		Elongation at failure							
		<50%	<50%	<50%	<50%	<50%	<50%	<50%	<50%
Harsh installation condition	Type 1	1400	900	500	350	500	350	3500	1700
Moderate installation condition	Type 2	1100	700	400	250	400	250	2700	1300
Less severe installation condition	Type 3	800	500	300	180	300	180	2100	950

Note:

(1) All numeric values in the above table represent Minimum Average Roll Value (MARV) in weaker principal direction. The MARV is derived statistically as the average value minus two standard deviations.

(2) When the geotextiles are joined together by field sewing, the seam strength shall be at least 60 percent of the material's tensile strength. All field seams shall be sewn with thread as strong as the material in the fabric.

(3) The puncture strength if determined in accordance with ASTM D 6241, the minimum requirement in terms of "Newton (N)" shall be as follows:

Table 8 Minimum requirement of Puncture Strength in different Condition

Installation condition as per Table 9	Strength property requirement (MARV)	
	Puncture Strength in Newton (N) as per ASTM D 6241.	
	Elongation at Failure	
	< 50 %	< 50 %
Harsh installation condition	2800	2000
Moderate Installation condition	2250	1400
Less Severe Installation condition	1700	1000

Table 9 Required Degree of Survivability as a Function of Subgrade Conditions, Construction Equipment, and Lift Thickness [18]

	Low ground-pressure equipment ≤25 kPa (3.6 psi)	Medium ground-pressure equipment > 25 to ≤50 kPa (>3.6 to ≤7.3 psi)	High ground-pressure equipment >50 kPa (>7.3 psi)
Subgrade has been cleared of all obstacles except grass, weeds, leaves, and fine wood debris. Surface is smooth and level so that any shallow depressions and humps do not exceed 450 mm (18 in.) in depth or height. All larger depressions are filled. Alternatively, a smooth working table may be placed.	Less Severe Installation condition	Moderate Installation condition	Harsh installation condition
Subgrade has been cleared of obstacles larger than small to moderate-sized tree limbs and rocks. Tree trunks and stumps should be removed or covered with a partial working table. Depressions and humps should not exceed 450 mm (18 in.) in depth or height. Larger depressions should be filled.	Moderate Installation condition	Harsh installation condition	Harsh installation condition

Minimal site preparation is required. Trees may be felled, delimbed, and left in place. Stumps should be cut to project not more than ±150 mm (±6 in.) above subgrade. Geotextile may be draped directly over the tree trunks, stumps, large depressions and humps, holes, stream channels, and large boulders. Items should be removed only if placing the geotextile and cover material over them will distort the finished road surface.	Harsh installation condition	Harsh installation condition	Not recommended

Note:

Recommendations are for 150 to 300 mm (6 to 12 in.) initial lift thickness. For other initial lift thicknesses:

300 to 450 mm (12 to 18 in.): reduce survivability requirement one level;

450 to 600 mm (18 to 24 in.): reduce survivability requirement two levels;

>600 mm (24 in.): reduce survivability requirement three levels.

For special construction techniques such as pre-rutting, increase the geotextile survivability requirement one level. Placement of excessive initial cover material thickness may cause bearing failure of the soft subgrade.

Ultraviolet Stability Requirements:

The material shall satisfy the ultraviolet stability requirements.

Table 10 Requirements for Ultra Violet Stability

Sr. No.	Properties of Fabric	Requirements (Retained Strength)
1	Grab Strength	Not less than 70% after 500 hours of exposure
2	Tear Strength	
3	Puncture Strength	
4	Burst Strength	

Table 11 Geotextile Requirements for Subsurface Drainage

In-situ passing 0.075 mm sieve (%)	Permittivity, per sec, as per ASTM D 4491/ IS 14324: 1995	Maximum Apparent opening size, mm ASTM D 4751/ IS 14294 : 1995
<15	0.5	0.43
15 to 50	0.2	0.25
>50	0.1	0.22

4.4 Foundation and Backfill soil properties- The value of cohesion 'c' and angle of internal friction 'Φ' vary for different backfill and foundation materials. These values shall be determined by carrying out tests in laboratory. In case of absence of the soil properties, values given in IS 14458-Part 2 may be used.

4.4.1 *Retained Fill*

The type of materials to be used for filling behind abutments and other retaining structures should be selected with care. A general guide for section of filling material of group has been given in **Table 12** as per IS 1498.

Table 12: Classification and identification of soils [6]

Sr No.	Soil Group	Unit dry weight(g/cm^3)
1	GW	2.00-2.16
2	GP	1.84-2.00
3	GM	1.92-2.16
4	GC	1.84-2.08
5	SW	1.76-2.08
6	SP	1.60-1.92
7	SM	1.76-2.00
8	SC	1.68-2.00
9	ML, MI	1.52-1.92

4.4.2 Fill for reinforced soil: The fill in the reinforced soil zone shall have drained or effective angle of friction not less than 30°, measured in accordance with IS: 2720 (Part 13), by conducting a drained direct shear test. In case the fill material has 25 percent or more particles of 4.75 mm or larger, drained shear test using large shear box may be conducted (IS: 2720: Part 39). The gradation of fill soil shall be as per following limits.

Table 13 The Gradation of Fill Soil

Sieve Size	Percentage Fine
75 mm	100 %
425 micron	60-90
75 micron	<15
PI ≤6	

Materials with more than 15 percent passing 75 micron sieve, but less than 10 percent of particles smaller than 15 microns are acceptable provided PI is less than 6 and angle of friction is not less than 30 degree.

In many applications where the retained fill such as Clayey / Sandy Gravel (residual soil) locally called as 'murram', classified as GC, GM or GC-GM may be used provided the fines content (defined as combined percentage of silt and clay) does not exceed 20 %.

5 SOIL REINFORCEMENT UNITS FOR RETAINING STRUCTURE

Mechanically woven double twisted steel wire mesh units used for soil reinforced and slope consolidation. For structures with vertical facing units are made with a hexagonal wire mesh continuous base panel for the reinforcement and facing portion of the structure. Mechanically woven double twisted steel wire mesh unit and continuous base panel is divided into two cells by means of a diaphragm positioned at approximately 1 m centres **(Fig. 6)**. The diaphragm shall be secured in position to the base so that no additional lacing is necessary at the job-site. The facing section of the unit is formed by connecting the back panel and a diaphragm to the main unit.

Mechanically woven double twisted steel wire mesh units are combined with high strength geogrid when only mesh tensile strength is not sufficient to resist forces. Vertical facing units are combined with high strength geogrid which act as primary soil reinforcement and continuous base panel act as secondary reinforcement with friction **(Fig. 7** and **8)**. Vertical facing RS unit is held by friction between the facia and primary reinforcement. Structure shall be designed based on results of pullout test as per ASTM D 6638. In case, facia is connected to reinforcement using mechanical connection, a reduction factor for joint strength must be included. The test procedure to be followed is a sustained ASTM D5262 test. Note that this test is to be conducted for 1,000 hours at a minimum as mentioned in GRI Standard Practice GG4(b). The connection between the facia and the reinforcement shall provide for 100 % of the long term design strength of the reinforcing element in continuity.

Reinforced Soil (RS) wall / slope facia can be built with a stepped or vertical face, with or without a batter. These RS structures are designed for sites and situations where it is

necessary to reconstitute the soil mass and where stone filling is scarce or expensive to obtain. Vertical facing RS wall and slope shall be designed as per and IRC:SP:102 and BS8006.

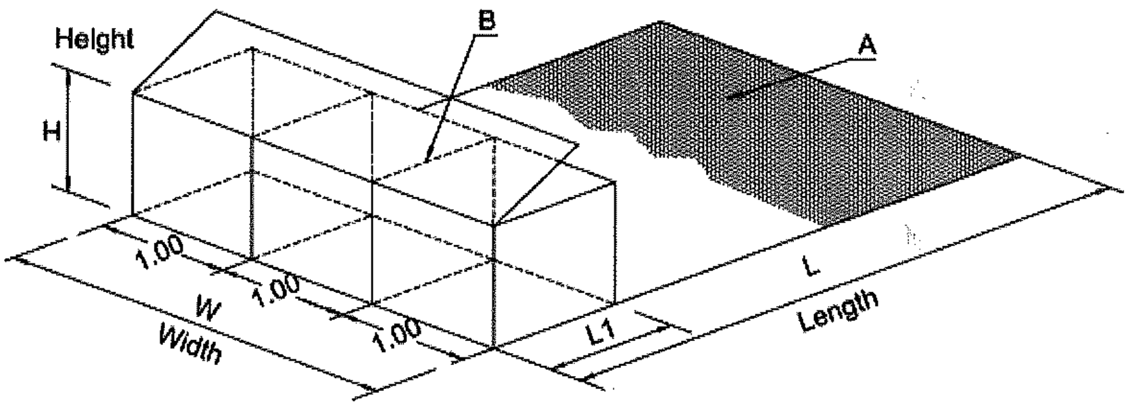


Fig. 6 Gabion Facia units for facing of Reinforced Soil Structures

A- Continuous base panel / integrated tail / reinforcing panel forming lid, external face and reinforcement, B-diaphragm, H – Height, L -Length, L1-Thickness of facing- W-Facia Width

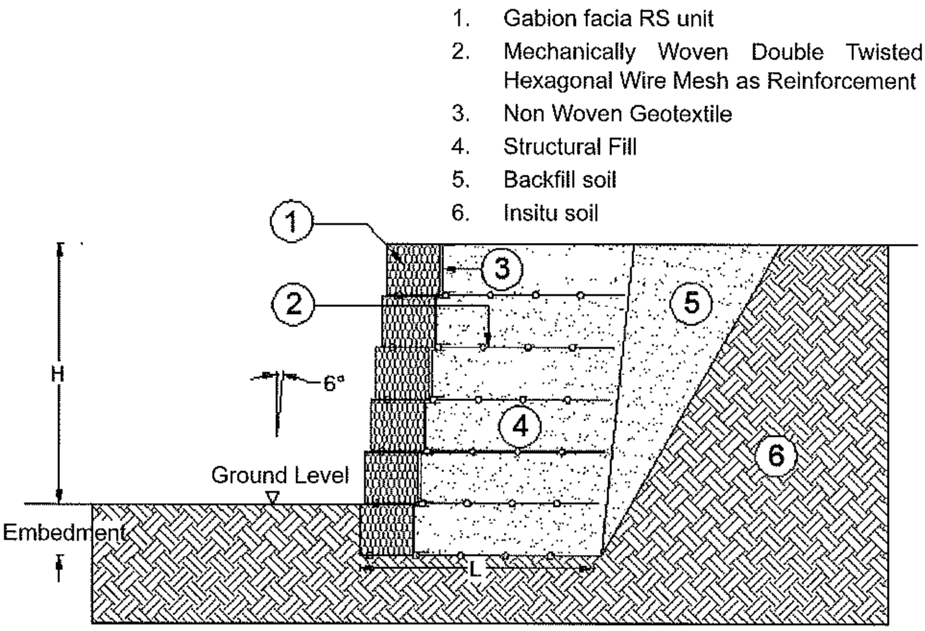


Fig. 7: Typical Photo of Reinforced soil wall with Gabion Facia

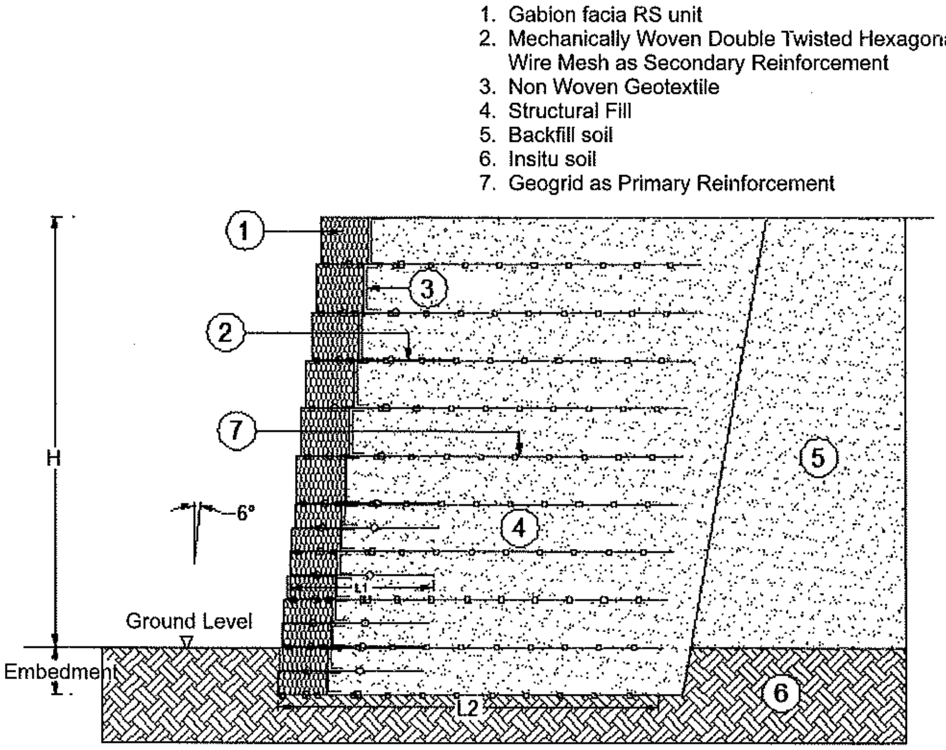


Fig. 8: Typical photo of Reinforced Soil Wall with Gabion Facia with Geogrid

Gabion, revert mattress and RS gabion unit galvanization and polymeric coating can be selected based on site environment condition. Double twist wire mesh products immersed in water in contact with alkaline solutions, or products which are subject to erosion (sand storms,…) shall be galvanized with zinc alloy and plastic coated. In these cases, assumed working life shall be evaluated between purchaser and supplier.

Table 14 Description of environment of installation site, coating wire requirements [17]

Site Environment level (a) **[in accordance with EN ISO 9223, Table 1]**	**Polymer coating(c)**	**Metallic Coating (b)**	**Assumed maximum working life of the product [Year]**	**Type of Structure**
Medium Aggressive (C3) Low Aggressive (C2)	-- --	Zinc	10 (C3) 25 (C2)	T / R
Wet Conditions (C4) Medium Aggressive (C3) Low Aggressive (C2)	-- -- --	Zn 95%/Al 5%alloy	10 (C4) 25 (C3) 50 (C2)	T / R

High Aggressive (C4) Medium Aggressive (C3) Low Aggressive (C2)	-- -- --	Zn 90%/Al 10%alloy	25 (C4) 50 (C3) 120 (C2)	T / R T / R P
Very High Aggressive (C5) High Aggressive (C4) Medium Aggressive (C3)	PVC / PA6	Zn 95%/Al 5%alloy	120	P
Extreme Aggressive (CX) Very High Aggressive (C5) High Aggressive (C4) Medium Aggressive (C3)	PVC / PA6	Zn 95%/Al 10%alloy	120	P

T - Temporary structure, R – Replaceable structure like launching apron which is accessible and can be replaced or repaired. P- Permanent structure having life 100 years or more like bridge approaches, wing walls, return walls, false abutment which cannot be replaced.

PVC – Polyvinyl chloride, PA6 - Polyamide

Low Aggressive: (C2) Dry conditions - Temperate zone, atmospheric environment with low pollution, e.g. rural areas, small towns (over 100 m above see level). Dry or cold zone, atmospheric environment with short time of wetness, e.g. deserts, sub-arctic areas.

Medium aggressive: (C3) Dry conditions Temperate zone, atmospheric environment with medium pollution or some effect of chlorides, e.g. urban areas, coastal areas with low deposition of chlorides, e.g. subtropical and tropical zone, atmosphere with low pollution.

High aggressive: (C4) Wet conditions Temperate zone, atmospheric environment with high pollution or substantial effect of chlorides, e.g. polluted urban areas, industrial areas, coastal areas, without spray of salt water, exposure to strong effect of de-icing salts, e.g. subtropical and tropical zone, atmosphere with medium pollution industrial areas, coastal areas, shelter positions at coastline.

Very High aggressive: (C5) Wet conditions Temperate and subtropical zone, atmospheric environment with very high pollution and/or important effect of chlorides, e.g. industrial areas, coastal areas, shelter positions at coastline.

Extreme aggressive: (CX) Subtropical and tropical zone (very high time of wetness), atmospheric environment with very high pollution SO2 (higher than 250 µg/m3) including accompanying and production ones and/or strong effect of chlorides, e.g. extreme industrial areas, coastal and off shore areas, occasionally contact with salt spray.

(a)	Gabion products immersed in water (saline and/or polluted water) and/or in contact with alkaline solutions, or gabions which are subject to abrasive conditions (sand storms,...) shall be metallic coated with polymer coating or shall be made from stainless steel wire.
(b)	Metallic coating shall be heavily coated wire as per IS 4826 or class A as per ISO 7989-2. There exist more advanced metallic coatings with a superior corrosion resistance. In terms of salt spray performance (ISO 9227), it means that the mesh samples shall not show more than 5% of DBR (Dark Brown Rust) after 2000 hr exposure on the surface. When subjected to test in sulphur dioxide environment (ISO 6988), mesh samples shall not show more than 5% of DBR after 56 cycles of discontinuous test on the surface. Assumed working life values will, therefore, be improved depending upon the prevailing conditions.
(c)	More advanced organic coatings with an equivalent or superior corrosion protection may be considered in order to improve the assumed working life.

6 DESIGN PRINCIPLE OF GABION RETAINING WALL

Gabion structure is a simple flexible gravity retaining structure, which retains soil with its weight. Gabion walls are designed on the same principle as gravity mass wall. The gabion structure should be designed in such manner that gabion mesh can hold the rock within with limited deformation which does not affect asthetics and internal stability. Limit state principles are used for design of gabion walls. Based on the requirement at the site, the gabion walls can be designed with several configurations such as (a) with stepped outside or (b) as stepped inside or (c) offset as shown in **Fig. 9a** to **9c**. The latter is preferable from economy, but site constraints predominate.

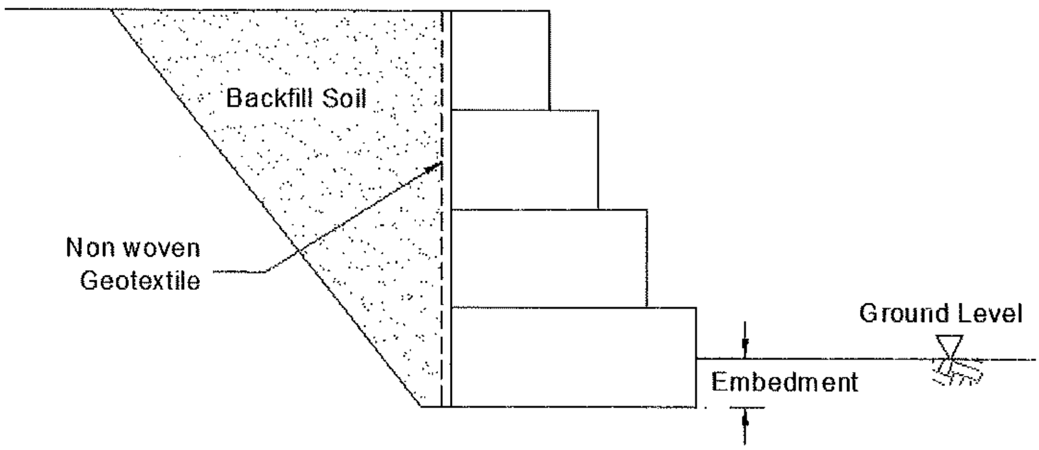


Fig. 9a: Typical Cross Sections of Gabion Wall with Stepped

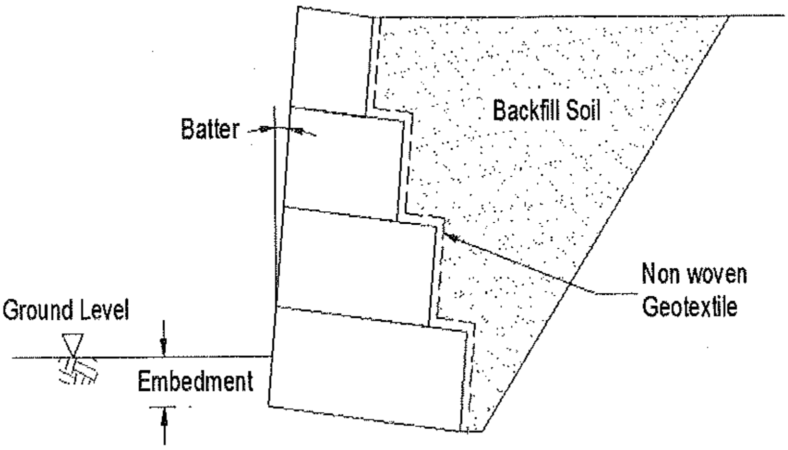


Fig. 9b: Typical Cross Sections of Gabion Wall with batter Angle

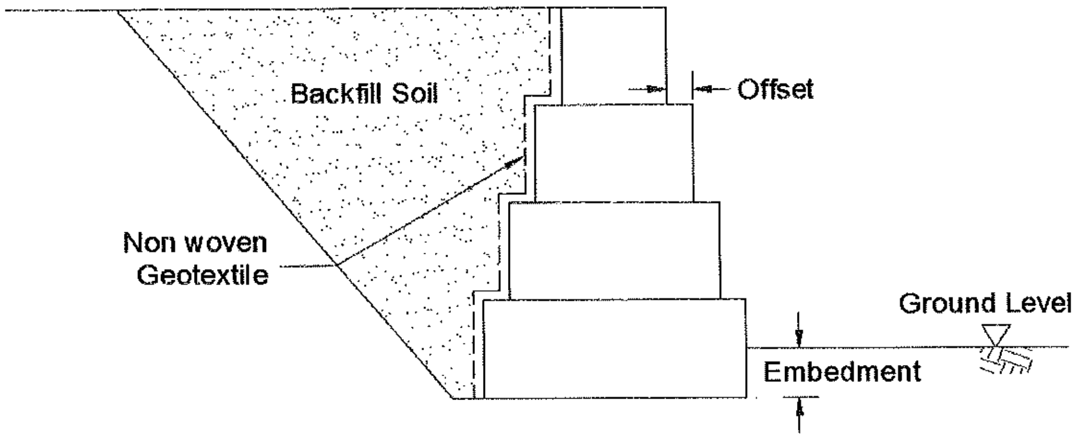


Fig. 9c: Typical Cross Sections of Gabion Wall with Offset

The gabions are designed as the gravity retaining structures and analysed as follows. Before the design of the gabion structure, the important parameters which are basic for the design have to be worked out. These include:

a) Foundation soil properties
b) Retained soil properties
c) Drainage requirements
d) Rock (to fill gabions) properties
e) Base width
f) Embedment depth
g) Batter angle
h) Loading
i) Extent of backfill
j) Seismic loading
k) Porosity of Gabion

6.1 Drainage Bay for Gabion

Unlike concrete structures, retaining walls or reinforced walls, there is no need to provide any drainage system for Gabion walls, as the gabion itself is porous and can drain freely. In order to prevent ingress of soil into the pores of the gabion wall, a filter, preferably a nonwoven geotextile should be provided between the gabion and the backfill as shown in **Fig. 10**. It is advisable to take measures to improve the drainage in the back of the wall using boulder/gravels/coarse grain material at the lower level of the fill and possibly providing a catch water drain for conveyance of collected water to convenient location **(Fig. 11)**.

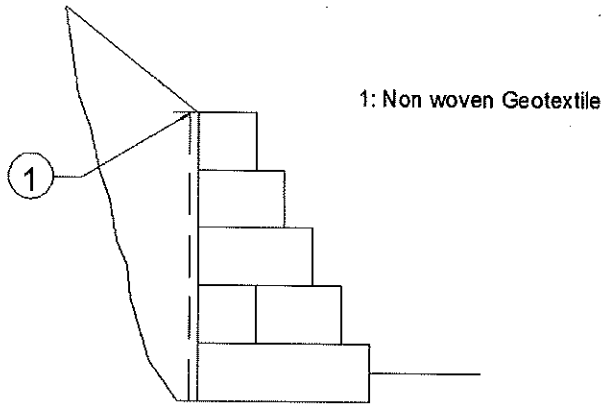


Fig. 10: Use of Non-Woven Geotextile in Gabion Retaining Wall as Filter Media for Drainage

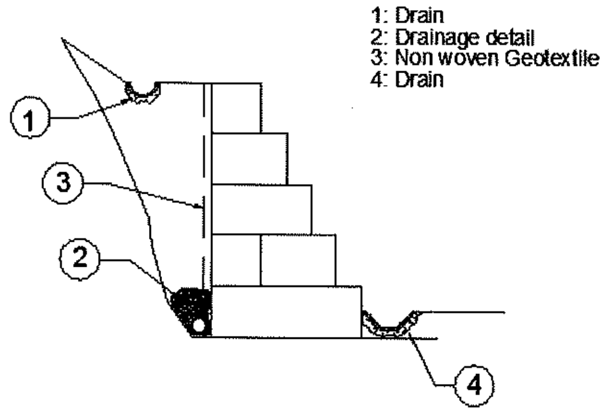


Fig. 11: Drainage System for Gabion Retaining Wall for Heavy Rainfall Condition

In fine silty or sandy soils, it is important to select a filling material which can serve as a filter to prevent migration of the soil through the structure. It is advisable to use non woven geotextile against the rear face of the wall which act as filter and prevent washing out of backfill. The geotextile material should be preferably non-woven **type III** meeting requirements mentioned in section 4.3. The use of nonwoven geotextile **type 1** shall also be used in river and marine works where a continuous and frequent water movement will flush the wall and the soil behind it. Nonwoven geotextile is sometimes useful for providing a filter between the excavated surface and the backfill and for preventing the washout of fines from the foundation **(Fig. 12)**.

Natural gullies shall be diverted away from the wall site so that flow of rain water does not cause erosion of walls on topmost terrace. Grass turfing shall be laid on the ground slope to prevent erosion.

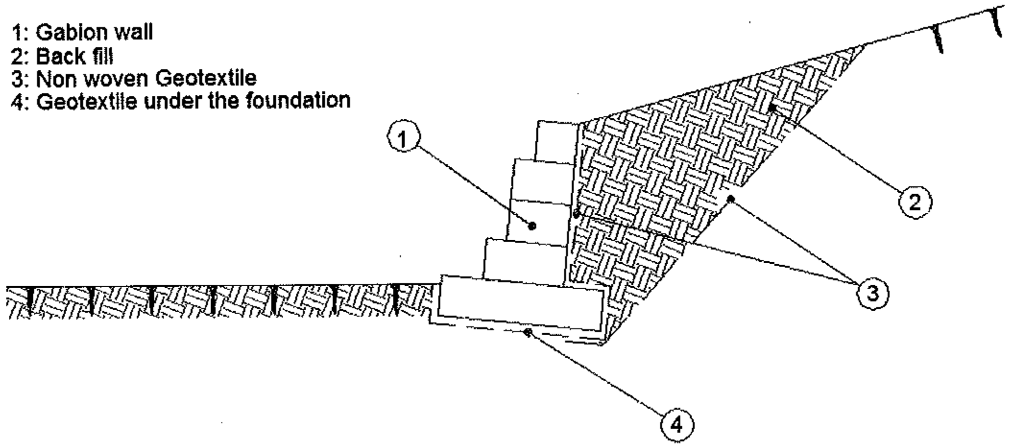


Fig. 12: Use of Non-woven Geotextile in Gabion Retaining Wall

6.2 Base Width

The base width of the Gabion wall for height 1 m to 6 m should recommended as 0.6 to 0.75 H and for above 6 m to 10 m it should be 0.55-0.65 H and shall satisfy the design requirement.

6.3 Embedment Depth

The minimum embedment depth of Gabion retaining wall should be minimum 0.5 m for flat ground condition for height 1m to 6 m and 1m embedment depth for height 6 m to 10 m shall be provided as per IS 14458 Part 1.

Larger values may be required, depending on the depth of frost penetration, shrinkage and swelling of foundation soil, seismic activity and scour. Minimum embedment depth of 0.5 m is required for any structure except for structures founded on rock. Embedment depth of wall resting of rock can be reduced as excavation in rock will be difficult. In such case embedment depth can be 0.3m – 0.5m with foundation may be levelled using concrete and some dowels may be provided.

6.4 Batter Angle

Batter of Gabion wall with respect to vertical can be considered as 3 to 6 degrees with vertical. Also, gabion wall can be constructed with vertical gabions and offset maintained on outer side **(Fig. 9b)**.

6.5 Loading

Retaining wall shall be designed for live load surcharge equivalent to 1.2 m earth wall as per IRC:6. Application of earth pressure force as per Coulomb's theory should be applied at H/3 from base of the wall. Gabion wall is more flexible compared to rigid R.C.C retaining wall, the inertial effects due to horizontal acceleration is considered wedge of earth and vertical

acceleration is neglected. Also only 50 percent of dynamic increment on the earth pressure of retained fill is considered. Peak horizontal acceleration is selected based on the seismic zone (design earthquake) given as A, Acceleration co-efficient [refer IS:1893]

6.6 Porosity of Gabion

A maximum porosity of 40 percent can be considered for the design of gabion purpose. In general, 35% to 40% porosity can be achieved. Porosity of gabion can be minimized by using rock sizes mentioned in 4.2 and using small size rock / stone chips filling voids between stones.

6.7 Extent of Backfill

Selected backfill shall be extended till 45+Φ/2 line from toe of Gabion which meets the top surface [as per IRC:78] as presented below in **Fig. 13**.

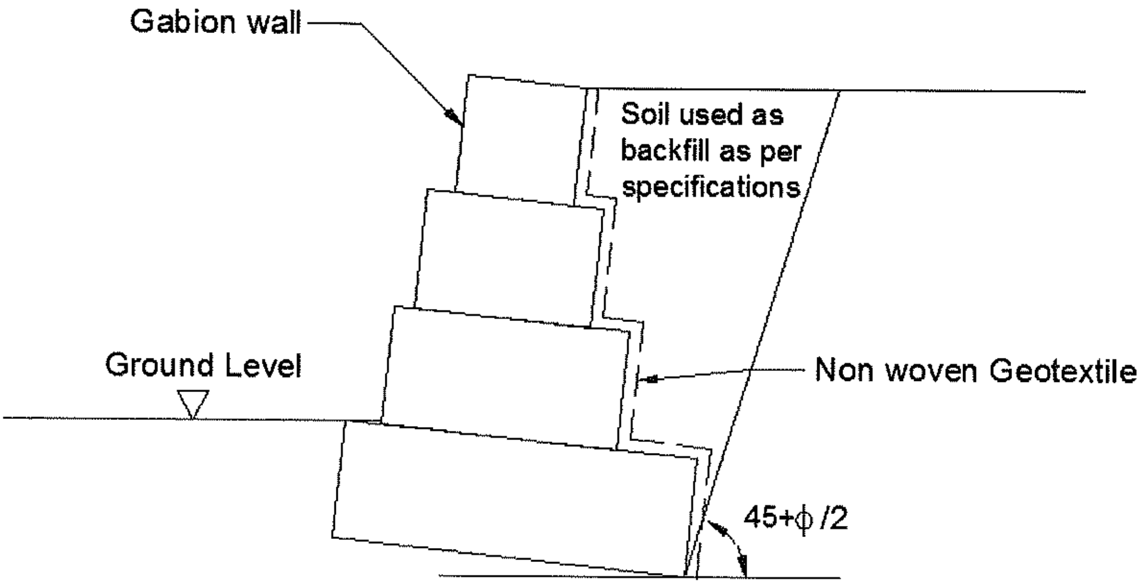


Fig 13: Extent of Backfill

6.8 Stability of a Retaining Structure

Based on height of the wall (H), trial design has to be performed, with minimum width of 0.5 m on the top and the width increasing with depth, in steps, as it reaches to the foundation level. It is recommended that the increment in the width should not be more than 1.0 m per step. This trial design must be checked against different types of failure. Final cross section of the wall shall satisfy all failure modes mentioned In the case of gravity retaining walls the main types of failure which may occur, are shown in **Fig.14**

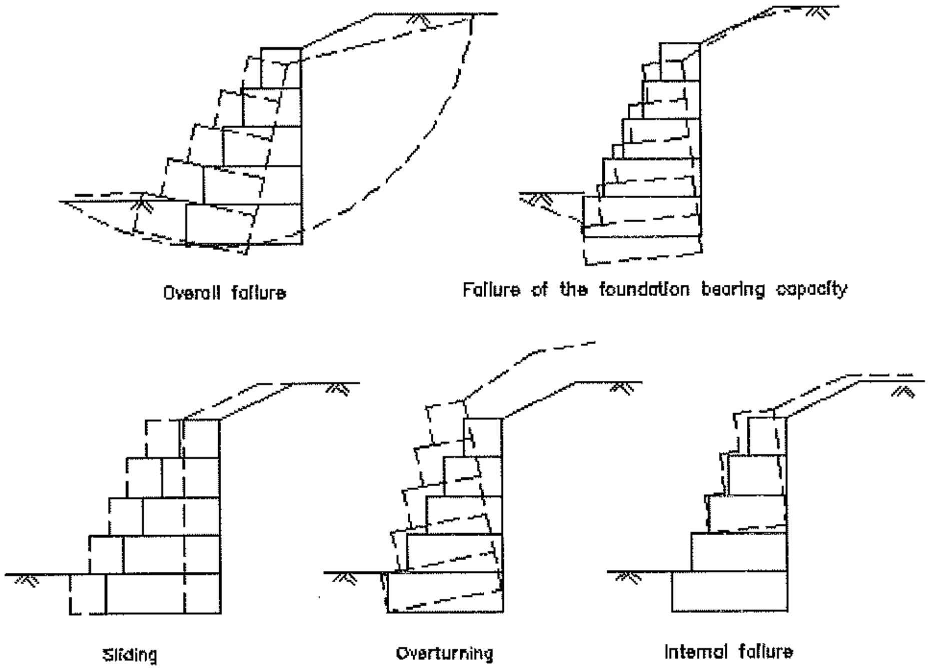


Fig. 14: Possible types of failure which may occur in gabion retaining walls

Stability of Gabion gravity retaining wall

The stability of Gabion gravity wall should be checked for the following condition:

- Check for overall stability (Global stability)
- Check for sliding
- Check for overturning
- Check for bearing capacity failure
- Check for internal stability of gabion layers

Table 15: Minimum Factor of Safety for the Stability Wall

Sr No	Recommended Factor of Safety for different stability checks	Static Case	Seismic Case
1	Global stability	1.3 for walls 1.5 for support abutments, building, important utilities	1.1
2	Sliding	1.5	1.125
3	Overturning	2	1.5
4	Bearing capacity	2 for walls 2.5 for support abutments, building, important structures	1.5 for walls 1.875 for support abutments, building, important structures
5	Internal stability	1.5	1.125

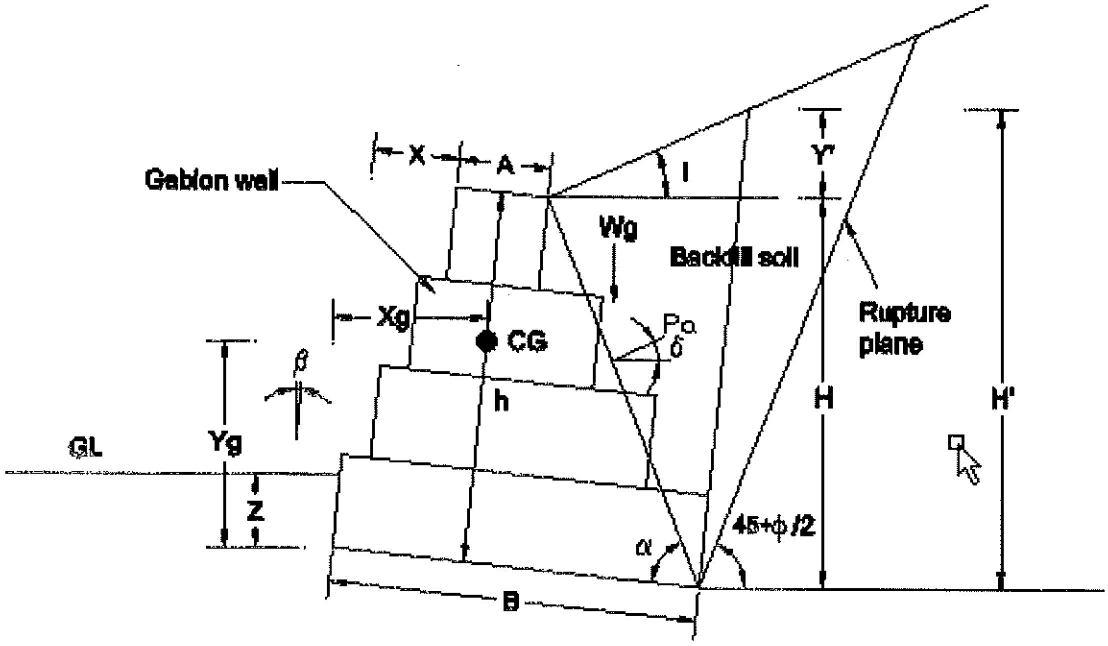


Fig. 15: Forces acting on the wall

α	=	effective plane at rear of the wall
φ	=	Slope of the retained soil
δ	=	Wall friction angle
Pa	=	Active thrust
Wg	=	weight of Gabions

With the above parameters, earth pressure in 'active' condition as per Coulomb's theory is computed based on the properties of the retained soil.

6.9 Determination of Active Thrust

Coulomb's theory is a method used to calculate the active and passive thrust acting on a retaining structure. It assumes that the soil total shear resistance is mobilized along the sliding and failure surfaces located within the soil mass. Coulomb's method assumes that such surfaces are plane and that the thrust acts on the most critical failure surface. Besides making it possible to analyse structures with a non-vertical internal front face, this method allows consideration of a possible friction between retaining structure and soil. In case of layered backfill,to determine the application point of the total active thrust, the soil parameters acting on the wall are assumed to vary linearly in each layer crossed by the active thrust.

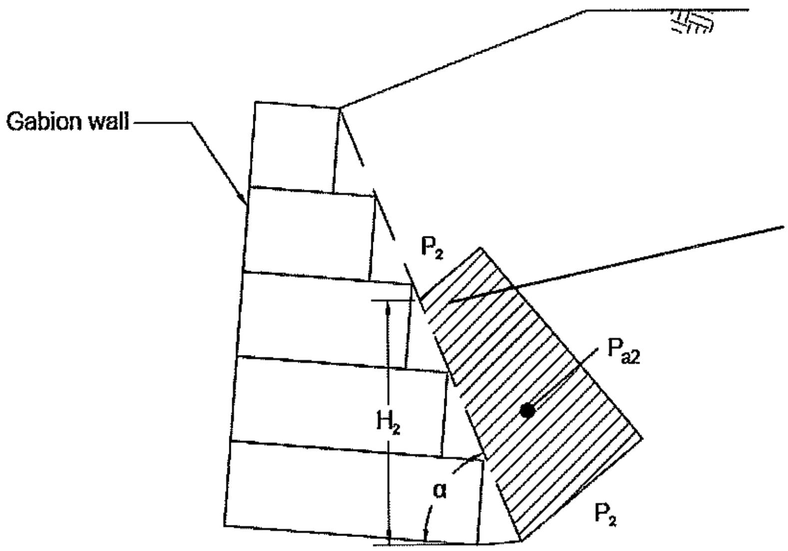


Fig 16: Application Point of the Thrust in the Soil Layers

The term of variation between lateral stress and the depth of the soil layer is given by:

$$\frac{dpa}{dh} = Y\,Ka$$

Where γ is the unit weight of the soil layer and Ka is the lateral earth pressure coefficient. This coefficient is determined by Coulomb's equation:

$$Ka = \frac{\sin^2(\alpha + \emptyset)}{\sin^2\alpha \times \sin(\alpha - \delta) \times \left(1 + \sqrt{\frac{(\sin(\emptyset + \delta) \times \sin(\emptyset - i)}{\sin(\alpha - \delta) \times \sin(i + \alpha)}}\right)^2}$$

Active thrust = Effect due to Earth pressure + Surcharge + Seismic

6.10 Safety against Sliding

The horizontal forces acting on the wall, due to soil and possible dead and live loads should be less than the frictional force at the base of the wall. The friction coefficient between the base of the gabion wall and the foundation soil can be tan φ' as gabion has rough surface in contact with foundation. Friction coefficient generally lies in the range of 0.5 to 1. Field tests showed friction coefficient value equal to tan (φ') [23]. Friction coefficient can be reduced by 15% when nonwoven geotextile is used at base of gabion wall. Sliding factor of safety, the ratio of the forces resisting sliding (due to the mass of the gabions W_g and the vertical component of active thrust P_v and the sliding forces due to the horizontal component of active thrust moment P_h ,on the plane of sliding, for the gabion wall should not be less than 1.5 in static condition.

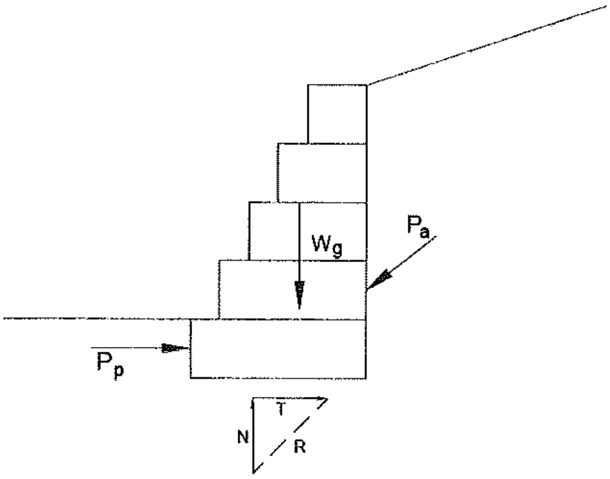


Fig. 17: Forces acting on a Retaining Structure

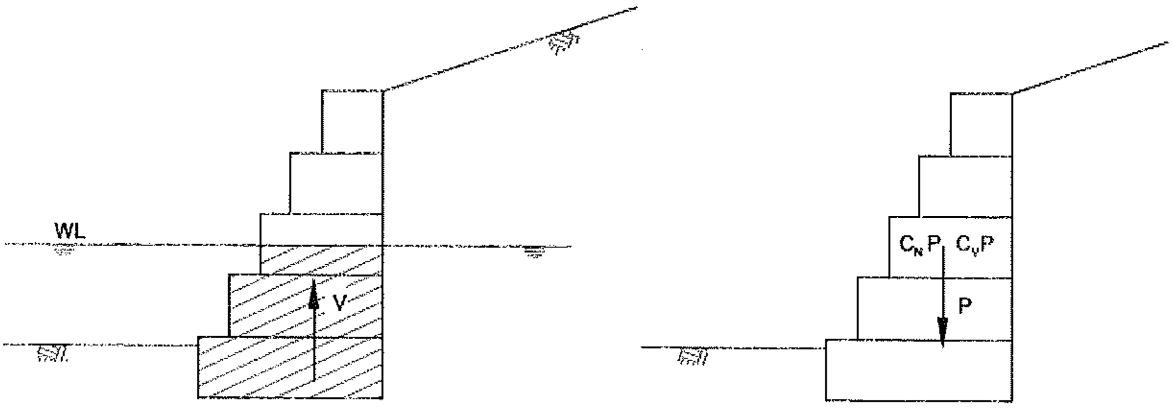


Fig. 18: Uplift Pressures and Inertia Forces

Both thrust Pa and Pp, the structure specific weight Wg and the foundation pressure R are the forces acting on the structure **(Fig. 17)**. The foundation reaction R may be divided into forces N and T respectively normal and tangential to the base of the retaining structure.

Beside these forces, one must consider other forces depending on external conditions. For example, if the structure is submerged either partially or totally, the uplift pressures V must be taken into account, whereas in the seismic analysis one must consider the horizontal and vertical forces. The surcharge loads are additional forces which may act directly upon the structure.

$$Safety\ factor\ against\ sliding = \frac{\mu * \text{Restoring Force(R)}}{\text{Sliding Force(S)}}$$

Where μ is coefficient of friction for sliding

6.11 Safety against Overturning

The moment is generated due to the lateral forces acting all along the gabion wall this

moment can overturn the wall, if properly not designed. The counter moments or the restoring moments are again due to the self-weight of the gabion wall, the vertical component of earth pressure force, the weight of the soil on the ledges, loads acting on the wall etc. Factor of safety against overturning, the ratio of the overturning moment and the restoring moments, for a safe condition, should be greater than 2.

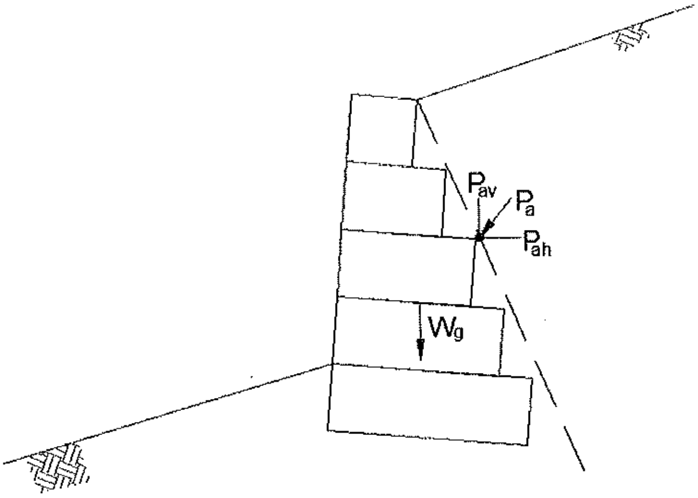


Fig. 19: Restoring and Overturning Moment

The forces which contribute the wall stability are:

- The structure unit weight,
- Passive thrust,
- Loads acting on the wall.
- Vertical component of the active thrust.

The inertia forces induced by the seismic effect and the uplift pressures which are involved when the wall is partially under water are considered in the calculation and contribute to decrease the restoring moment. The overturning moment is formed by the moment of the active thrust acting on the wall.

Safety Factor against Overturning= Resisting Moment (M_r) / Overturning Moment (M_{oh})

Where,

$M_r = M_w + M_{ov}$

$M_w = W_g \times X_g$

$M_{ov} = P_a \times \cos(\alpha - \delta - \beta) \times X_{pa}$

$M_{oh} = P_a \times \sin(\alpha - \delta) \times Y_{pa}$

Where,

M_w – Moment due to self-weight

Xg – Centroid of gabion wall

Wg –Total weight of gabion wall

Pa – Active earth pressure

α – Angle between horizontal and plane on which pressure acts

δ – Angle between line of action of earth thrust and perpendicular to the Plane on which pressure acts

β – Batter with vertical

Y_{pa} and X_{pa} – Lever arm of Pa from toe

6.12 Safety against Bearing

The pressure due to the dead load of the gabion walls should be within the permissible limits of the allowable bearing capacity of the foundation soil. Though due to the flexibility of the gabion walls, the settlements are not a major issue, care should be taken to estimate the settlements and the compensation for the same. In general, the foundation soil is subjected to a vertical force, a horizontal force and moment. Therefore, the resultant load amounts to an eccentric-inclined load. The base and other dimensions of the wall should be such that the resultant of the forces falls within the middle one-third of the base.

To calculate the pressures acting on the foundation of the structure, first determine both the point of application of the normal force N which is calculated during the check against sliding and the moment equilibrium with respect to the lower left angle of the base, which is given by:

$$d = \frac{(\mathrm{Mr} - \mathrm{Moh})}{\mathrm{N}}$$

Eccentricity from center of base, e = $\frac{\mathrm{B}}{2} - d$

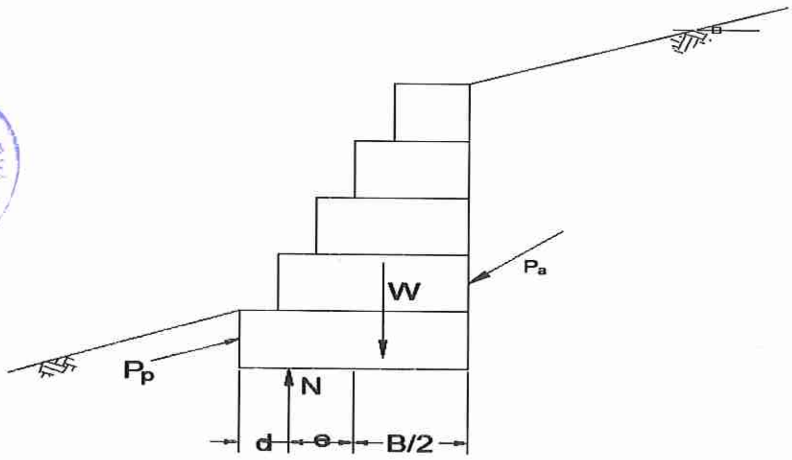


Fig. 20: Point of application of N

This normal force is the resultant of the normal pressures which act on the base of the retaining structure **(Fig. 20)**. Usually base pressures have a linear distribution with maximum and minimum values will be at the edges of the base of the wall.

The maximum and minimum stress is given by:

$$q_{max} = N/B\ (1 + 6\ e/B)$$
$$q_{min} = N/B\ (1 - 6\ e/B)$$

Where,

q_{max} and q_{min}–Maximum and minimum pressure on the foundation

N = Normal force at the base of the wall

B – Base width of gabion

e – Eccentricity at Normal base N with e ≤ B/6

d – Distance of reaction from centre of base

Maximum bearing pressure q_{max} should be less than the allowable bearing pressure of the foundation soil. Ultimate bearing capacity shall be calculated considering strip foundation with base width B.

q_{ult} = Ultimate Bearing Capacity

$$q_{ult} = cN_cS_c+qN_qS_q+0.5\gamma B_FN_\gamma S_\gamma W$$

Where,

N_c – Bearing capacity factor due to cohesion

S_c – Shape factor correction due to cohesion

N_q – Bearing capacity factor due to surcharge

S_q – Shape factor correction due to surcharge

N_γ – Bearing capacity factor due to weight of subsoil

S_γ – Shape factor correction due to subsoil weight

$$\text{Factor of safety} = \frac{\text{Ultimate Bearing Capacity (qult)}}{\text{Maximum pressure on foundation (qmax}}$$

A retaining wall should not be attempted if weight of backfill will exceed the allowable bearing pressure of the underlying soil. In such cases, light weight backfill (e.g. flyash) can be used to lower base pressure or the soft underlying soil should be replaced with compacted granular soil.

When the foundation soil is non-cohesive type, the minimum depth of the foundation can be limited to 0.5 m for low height walls. For high walls, the depth of embedment shall be increased. In case of cohesive ground, the embedment depth shall be more than 500 mm. It is recommended to lay a granular base to a thickness of 300-500 mm in case where the gabions are to be laid on cohesive soil, over which the gabion wall can be designed with the foundation properties same as the granular fill. However, it is strongly advised to estimate the settlement using the properties of the cohesive ground and compensate the height accordingly.

6.13 Safety against Internal Failure

The retaining structure must be checked against the possibility of internal failure since it is subjected to internal stresses due to the thrust and to the surcharge loads directly applied on the wall. The mechanism of internal failure can be divided according to the type of structure. In case of Gabion walls, check each layer shall be checked against sliding with respect to the layer above and below it (Fig. 21). For this analysis, one must determine the active thrust which acts on the wall portion above the analysed section.

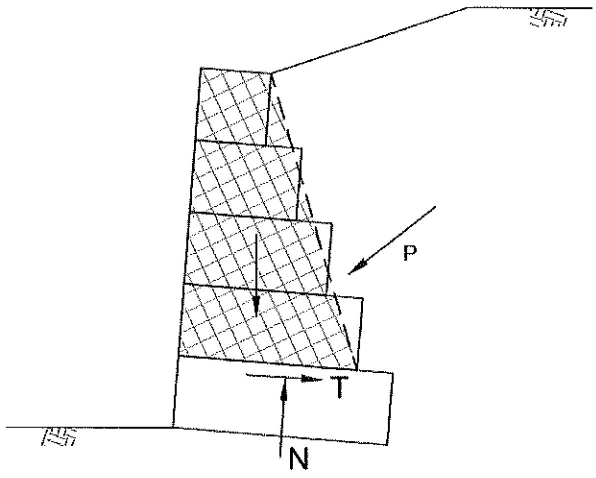


Fig. 21: Analysis of the Intermediate Layers

The shear and the maximum normal stresses acting on this section, are calculated by using the force and moment equilibrium,

The shear stress will be calculated as -

$$\tau = \frac{T}{B}$$

Maximum normal stress will be

$$\sigma_{max} = \frac{N}{2d}$$

Where ***B*** is the width of the gabion layer of the section analyzed and ***T, N*** and ***d,*** are obtained from the force and moment equilibrium. The allowable values of both shear and normal stress shall be calculated considering properties of mesh used for making gabion box. Gabion mesh provides confinement to stones which contribute in apparent cohesion and increased friction angle. These parameters shall be used by designed based on laboratory tests or experiments [22]. As explained earlier that the Gabion structure is flexible and permeable. While the settlements cannot be avoided, the gabions can adjust to the settled/deformed profile. Gabions can tolerate high differential settlements without losing integrity. Overall gabions wall settlement shall be assessed based on foundation soil properties. Also, deformation of gabion layers shall be assessed which is dependent on normal stress, properties of mesh like tensile strength, punch resistance, filling of gabion etc.

6.14 Safety against Overall / Global Failure

Besides the types of failure indicated above, gabion walls may be subjected to global failure along a failure surface external to the gabion walls. This type of failure may occur when the foundation consists soil layers with different characteristics, some less resistant than others

or, in case of walls protecting road embankments when downhill slope is inclined below the horizontal.

The stability analysis most commonly used assume the behaviour of the soil mass as a rigid body subjected to failure on curved surface.

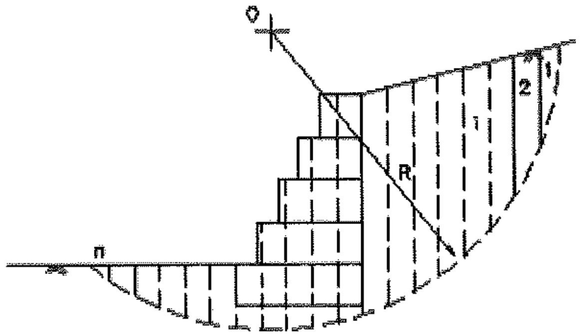


Fig. 22: Soil surface divided into slices (Bishops method)

Limit equilibrium method such as Bishop's simplified method of slices which refers to circular surfaces can be used (Fig. 22). In order to find critical surface with lowest factor safety computer program can be used as hand calculations will take longer time.

7 DESIGN PRINCIPLE OF GABION / REVET MATTRESSES

Before the design of the River structures with Gabions and mattresses, the important parameters for the design have to be worked out. These include -

a) Peak Velocity of flow
b) River bed gradient
c) Peak flood discharge,
d) Type of soil on the river bank and bed
e) River width
f) Different water levels (i.e .low, normal and high water levels)
g) River /Channel geometry.

Gabion or revet mattresses shall be used as revetments to prevent surface erosion only on geotechnical stable slopes. In case of slope instability, suitable stabilization measures shall be carried out.

7.1 Design Data

Discharge: The discharge for which river training works are to be designed shall be in accordance with the recommendations of IRC:5.

Scour depth: The mean depth of scour below the highest flood level shall be calculated in accordance with the provisions of IRC: 5

7.2 Thickness of the Mattress

Research and Development work carried out at Colorado State University Fort Collinsto test the performance of gabion mattress under various hydraulic conditions. This test was carried out both at full-scale and on scale-model to establish the behaviour and stability of channel revetment protected with Gabions and mattress. Based on the research results, the thickness of the mattress is selected considering the flow velocity that the mattress has to sustain slope angle ϕ the river bank and the average stone fill size that would be available for filling the mattress box. Indicative thickness of gabion mattress in relation to water velocity shall be given as per **Annexure II**. Selected thickness of mattress shall be checked for the tractive shear stress criteria i.e. the revetment stability check along the bed and slope portion.

7.3 Tractive Force Theory

Checks against erosive effects are satisfied when the actual (effective) shear stress generated by the flow at each section point in contact with flowing water is lower than the maximum allowable shear stress on the channel surface. The tractive force theory assumes that as the actual shear stress exceeds the maximum surface tolerable shear stress, a dynamic transport of colloidal and later larger aggregates occurs.

For revet mattresses placed on channel beds or banks, the shear stress on the mattress I calculated as follows [15]:

$$\tau_b = K_1 K_b \gamma_w y S_f$$

Where,

τ_b – Design shear stress

γ_w – Unit weight of water

y – Maximum depth of water on revetment in m

S_f – Slope of energy grade line (average river bed slope)

K_1 – slope factor: 1 for horizontal, 0.75 for sloped surfaces

K_b – Bend coefficient (dimensionless explained below)

The bend coefficient K_b is used to calculate the increased shear stress on the outside of a bend. This coefficient ranges from 1.05 to 2.0, depending on the severity of the bend. The bend coefficient is a function of the radius of curvature Rc divided by the top width of the channel T, as follows:

$K_b = 2.0$	for $2 \geq Rc/T$
$K_b = 2.38-0.206\,(R_c/T) + 0.0073(R_c/T)^2$	for $10 > Rc/T > 2$
$K_b = 1.05$	for $Rc/T \geq 10$

The recommended procedure for determining the permissible shear stress for a gabion mattress is determined as follows.

$$\tau_c = K_s C_s (\gamma_s - \gamma_w) d_{50}$$

Where,

τ_c – Permissible shear stress

C_s – Shield for rock-filled revet mattress equal to 0.10

Ks – reduction factor for revert mattress on slope $Ks = \sqrt{1 - \frac{\sin^2\theta}{\sin^2\varphi}}$

θ bank slope ϕ soil friction angle

γ_s – Unit weight of the rock fills (22-26 kN/m^3)

γ_w – Unit weight of water

d_{50} – Median diameter of rockfill in mattress

The coefficient C_s is an empirical coefficient developed by Maynord (1995) from test data presented in Simons et al. (1984). Use of C_s = 0.10 got gabion / revet mattress, in which ratio of maximum to minimum stone size ranges from 1.5 to 2.0. Higher C_s may be used when testing carried out such materials. Shear stress on bed shall be less than permissible shear stress.

$$\tau_b < \tau_c$$

Toe Protection: Toe protection may be provided such that the mattress on the slope shall not slide due to undermining and scouring at the toe. For toe protection, mattresses in the form of launching apron or toe wall shall be provided based on the severity of the scour. Thickness of launching apron may be considered as 20-50% more than the bank protection thickness provided on slope.

The thickness of the gabion mattress should be at least twice the average diameter of the rock fill, $T \geq 2d_{50}$. If the computed thickness does not match that of a standard gabion thickness, the next larger thickness of mattress should be used.

7.4 Design of Launching Apron

Launching apron should be laid at Low Water Level (LWL). The launching apron should be designed to launch along the slope of scour and provide a protection layer so that scouring is checked. The size of launching apron should be such that it should form a protection layer up to level of maximum scour depth. Slope of launching apron may be taken as 2H: 1V **(Fig. 24)**. Non-woven geotextile filter below the launching apron may also be provided.

Width of the launching apron depends upon the scour depth below HFL.

Depth of scour below HFL (D) may be worked out from the following formula.

$$D = 0.473\ (Q/f)^{1/3}$$

Where Q= design discharge in cumecs

f is silt factor. Silt factor (f) may be calculated using the following formula

$$f = 1.76\ (d)^{1/2}$$

Where,

d is mean particle diameter of river material in mm

Maximum scour depth (D_{max}) below HFL= 1.5* Scour depth (Dbelow HFL).

Maximum Scour depth (D_{max}) below LWL = (D_{max}) below HFL – (HFL-LWL)

Width of Launching Apron = 1.5 * Maximum Scour depth (D_{max}) below LWL

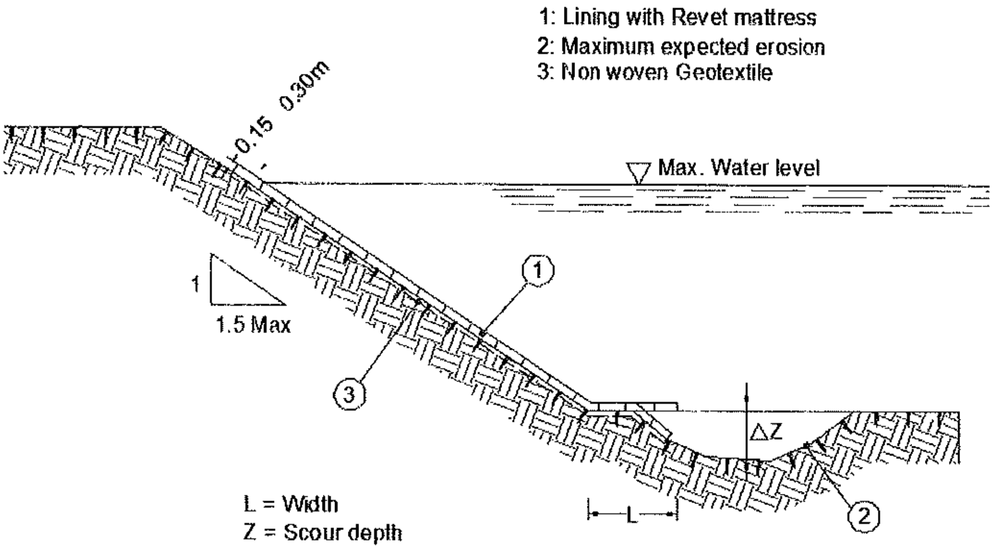


Fig. 23: Typical Section of Gabion Mattress for Lining

The best toe protection is obtained by extending the lining for a length 1.5 to 2 times the expected erosion at the most critical section **(Fig. 23)**.

$$(L) > 1.5 \text{ to } 2 \text{ Times } (\Delta Z)$$

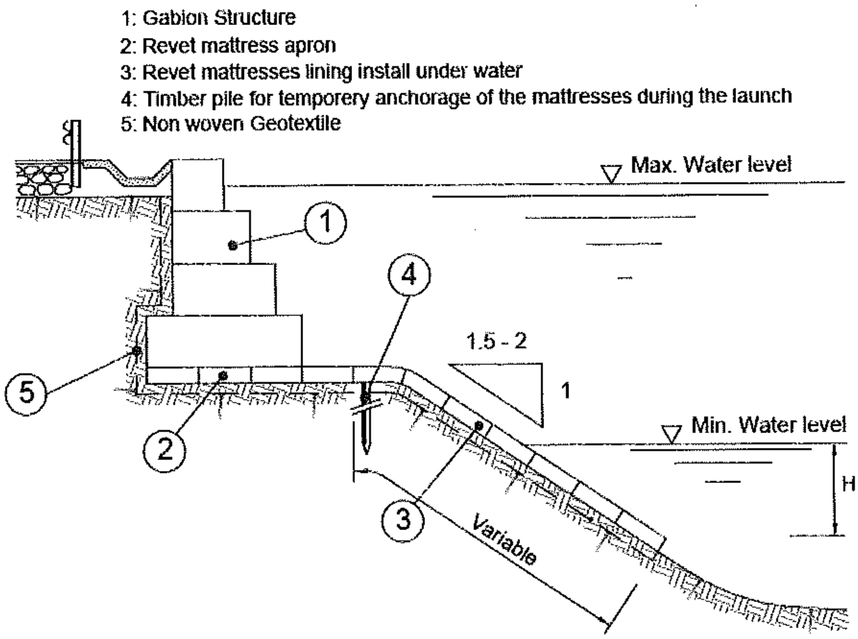


Fig. 24: Revet Mattress Foundation of a Retention and Protection Structure of a Road Embankment. The revet mattress were installed partially under water.

7.5 Lining application carried out under water

The installation of an embankment lining may have to be carried out in presence of the water on banks of large rivers, in the vicinity of the rivers and river deltas. In such cases, special attention shall be paid in order not to endanger the stability of the lining.

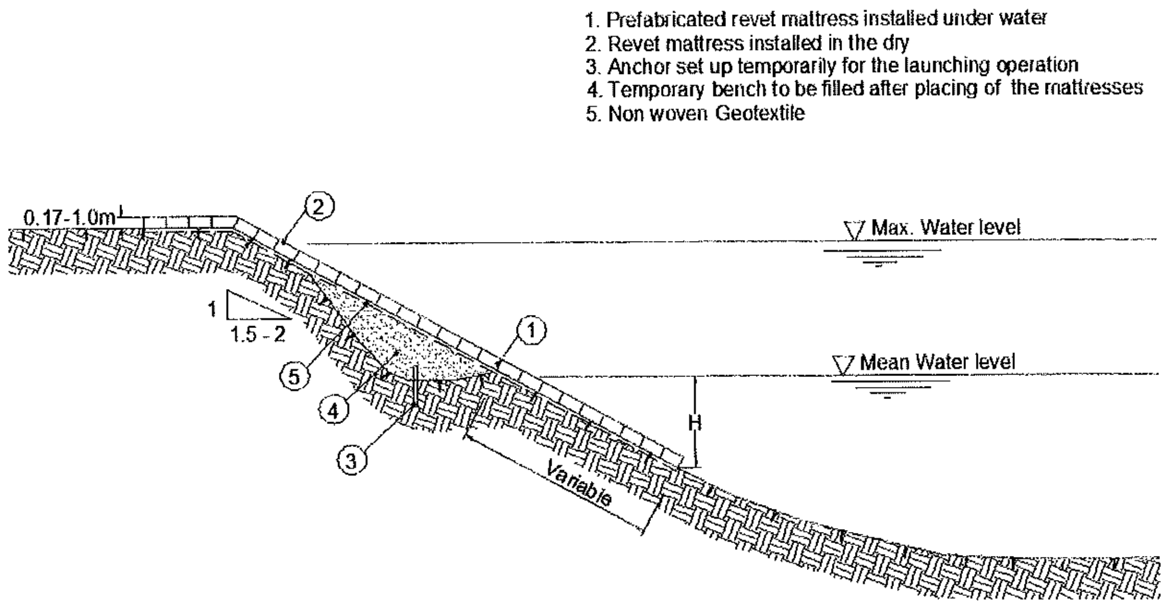


Fig. 25: Bank lining with revet mattress installed under the water

7.6 Structure with Deep Foundation

The wall must be founded at a level which is not affected by water scour problems. It is recommended where the river bed material is virtually in erodible or where it consists of solid rock **(Fig. 26)**. This type of foundation is appropriate where the rock and gravel deposits can provide adequate foundations.

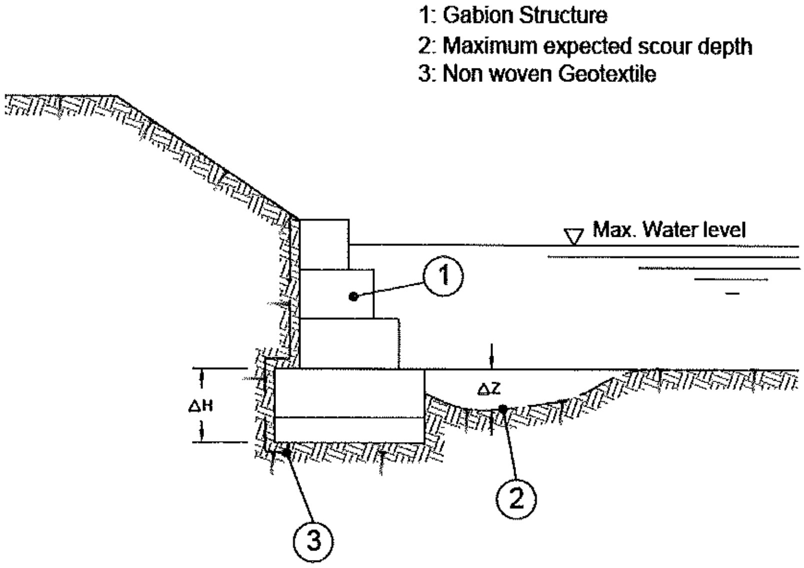


Fig. 26: Structure with Deep Foundation

Where, **Δz**-Scour depth, **ΔH**-Embedment Depth

7.7 Structure Built on Loose Rock or Cylindrical Gabion Platforms

It is not always possible to build the foundations of river bank improvements in the dry, platforms can be built of loose rocks or cylindrical gabions and vertical portion of the protective structure can be conveniently built on top **(Fig. 27** and **Fig. 28)**.

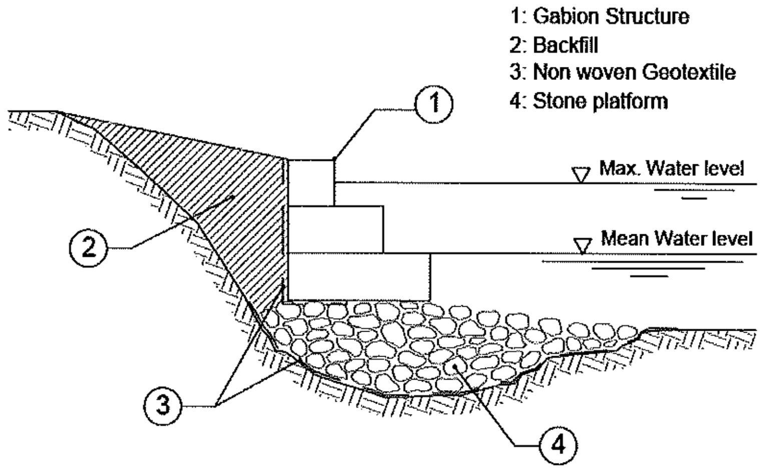


Fig. 27: Structure Built on Loose Stone

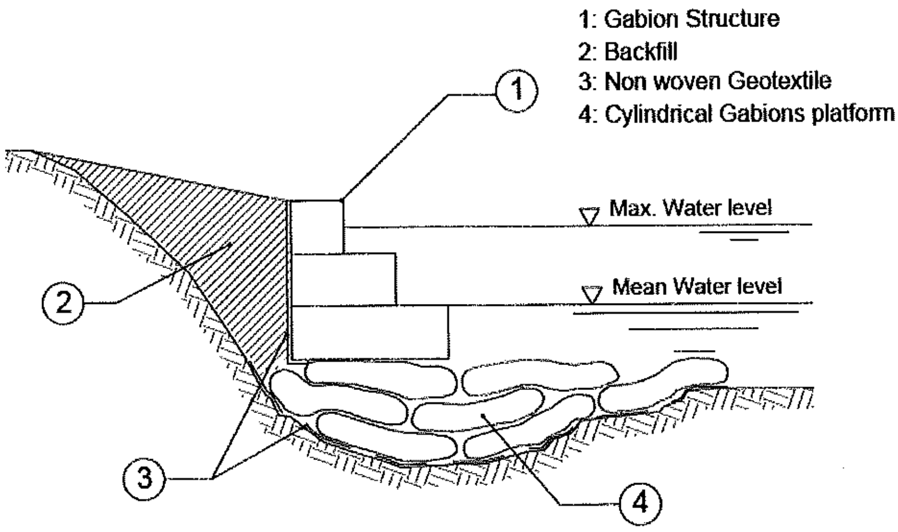


Fig. 28: Structure built on cylindrical gabion

7.8 Structure Built on Replaced Soil

When the foundation strata are weak/cohesive or soft soil, replaced soil or free drained soil used for backfill soil can be used for certain depth, ensure to satisfy the bearing capacity checks of the soil in the design. However, the bed soil replacement shall be feasible in case of continuously flowing river. In such conditions, the replacement or scour hole filling shall be made with cylindrical gabions or loose stones as shown in **Fig. 27** and **Fig. 29**.

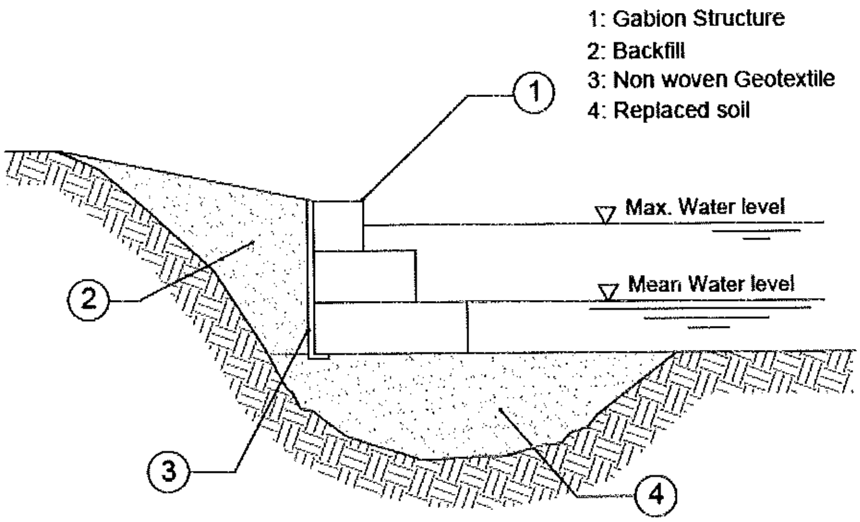


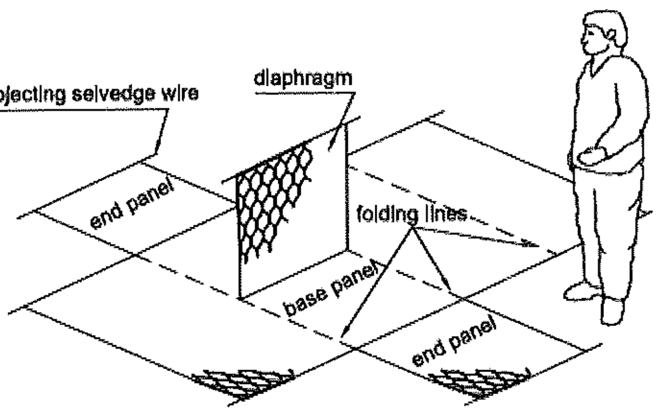
Fig. 29: Structure Built on Replaced Soil

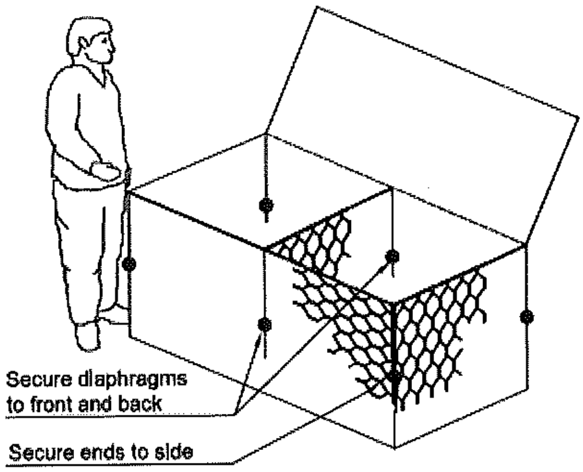
8 INSTALLATION METHODOLOGY OF GABION

Gabions are delivered at the work site in bundles along with the lacing wire. Bundles must be unloaded using any available machine and stored close to the site where they are to be installed. While unloading care shall be taken that Gabion bundles are not damaged. Maximum 4 bundles shall be stacked over each other. Gabion bundles shall be stacked on a leveled ground with wooden rafters/sleepers in between them for easy in handling and preventing any damage to the mesh and other components like the selvedge wire.Storage can be outdoors as long as the bundles are not laid over abrasive or chemically aggressive surfaces (corrugated asphalt, oils, grease, chemicals, etc.).

The following are the steps in the basic procedure for erection and installation of structures. At the work site bundles should be opened and gabions assembled according to the following instructions:

1) Excavate the formation to the required level as shown in the drawings. If good bearing stratum is not observed after the excavation up to mentioned levels then, the same should be brought to the notice of Engineer-in-charge for further advice. The surface of formation should be free from any deleterious material and unwanted foreign objects. Loose pockets if any, should be excavated and filled with suitable granular or backfill material.
2) The place should be cleared of standing water to ensure proper placement of gabions. In case dewatering is not possible then gabions shall be installed underwater.
3) Compact the formation using Vibro-roller of 8 to 10 tonnes capacity. Density of compacted formation should be greater than or equal to 95% of the modified Proctor value.
4) The outer alignment of the gabion facia should be marked by the survey team as per the requirements in the drawings.
5) The gabions are unfolded and laid over an even, level and hard surface (compact ground). One or two persons may be deployed for the straightening of mesh panel activity depending on the size of gabions. The gabions should be properly assembled and wired together, so that all four corners match and form an exact rectangular shape and size as designed **(Fig. 30a** and **b**).





Installation methodology of Gabion

Fig. 30a and30 b: Gabion Installation Steps

6) The side panels are opened up to form a box by tying the upper corner of each pair of side panels using the thick selvedge wires **(Fig. 31a)**.

7) The edges are laced together, starting from top corner, in a continuous operation using alternate single and double loop at the spacing of one mesh length i.e., 100 mm to 125 mm. The ends of the lacing wire are secured at each corner and turned into the gabions. Individual ties of lacing wire should not be used. Alternatively, steel rings mentioned IS16014 can be used which are attached using mechanical tool **(Fig. 31a** and **31b)**.

8) Similarly all the other sides are tied up and the box structure made, with the top end open to fill the boxes.

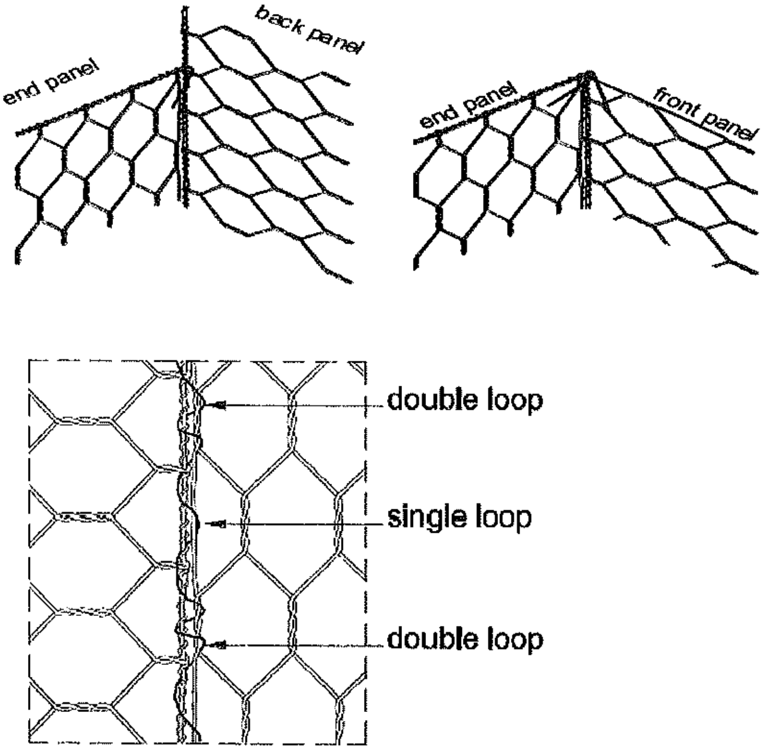


Fig. 31a: Assembling details with Lacing Wire

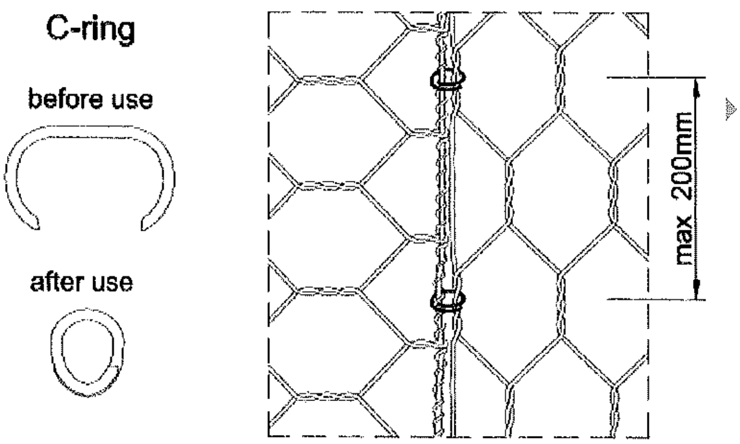


Fig. 31b: Assembling details with C-rings

9) The filling is then carried out with stones of dimensions larger than that of the mesh opening making sure that there are minimum voids. For better finish the stone fill to the front face is selected and placed carefully to give the best appearance. When using quarried/crushed rock, rock shall be selected in such a way that at least one face is flat-shaped. This will not be applicable when using rounded stone from rivers. Front loader or back loaders or excavator can be used to fill gabions maintaining porosity. For

a better alignment of the face, it is advisable to include internal tie wires while filling the gabions. This horizontal tie wires prevent gabion deformation during the filling stage.

Porosity check

The average porosity of the Gabion boxes can be found out by weighing the filled boxes. The weight of the box can be compared with calculated weight of box.

Let us assume the density of the stone (γ_s)= *26 kN/cum.*

In general porosity of the filled Gabion box shall be around (n) 30-40%.

Density of gabion would be $\gamma_g = \gamma_s * (1 - n)$ *ignoring air voids*

Assuming 35% porosity the density of gabion = 16.9 kN /cum.

Hence, weight of 1.5 x 1 x1 m Gabion box = 1.5 x 16.9 = 25.35 kN ~ 2.5 ton

The weight of the filled gabion box should be approximately equal to the calculated weight.

10) In case of one meter high boxes, gabions should be filled to one-third height and the tie wires fixed **(Fig. 32)**.The same sequence is repeated at two-third height. For 0.5 m high, gabion requires only one row of tie wires at half the height of the gabion.

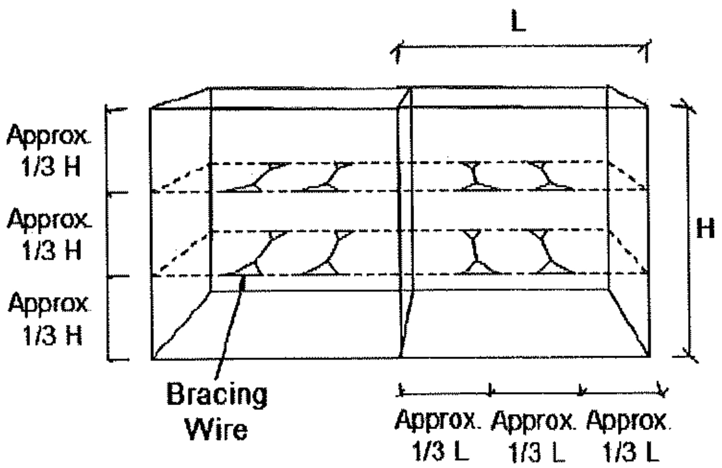


Fig. 32: Bracing wire details

11) The filled layer should never be more than 300 mm higher than any adjoining cell. To avoid such circumstances the filling pattern shown in below **Fig. 33** should be followed The Gabion is over-filled by approximately 25 mm to 50 mm, to allow for settlement of the infill (due to self-weight).

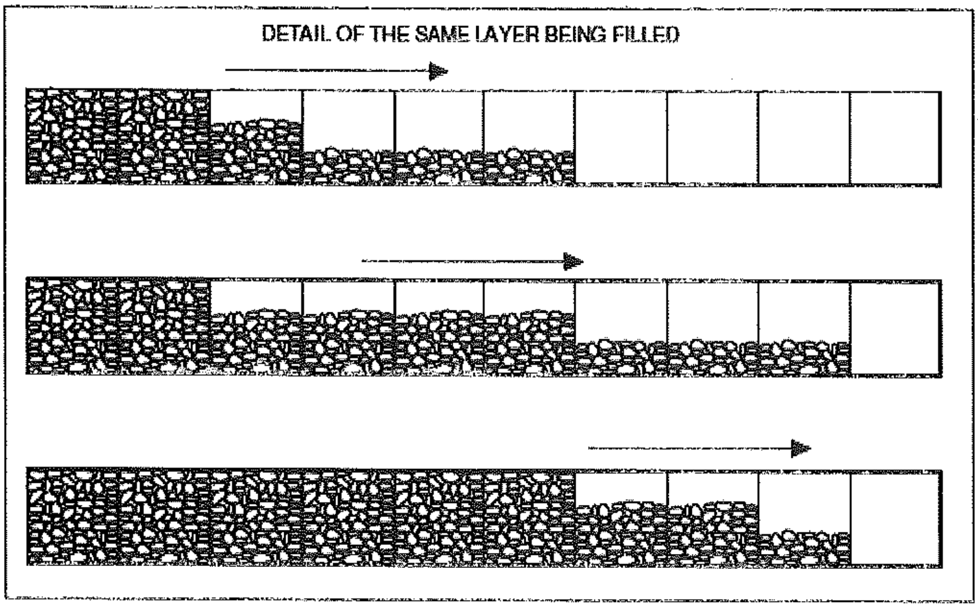
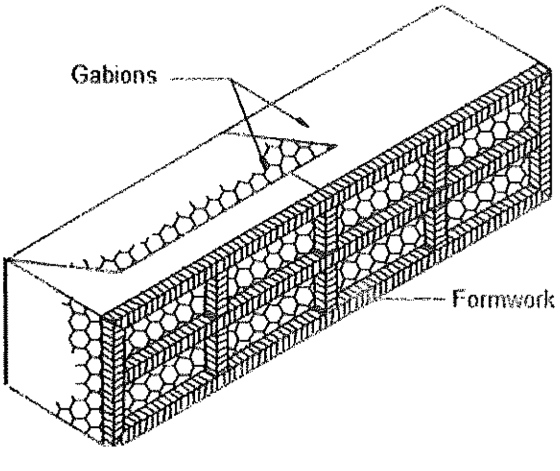
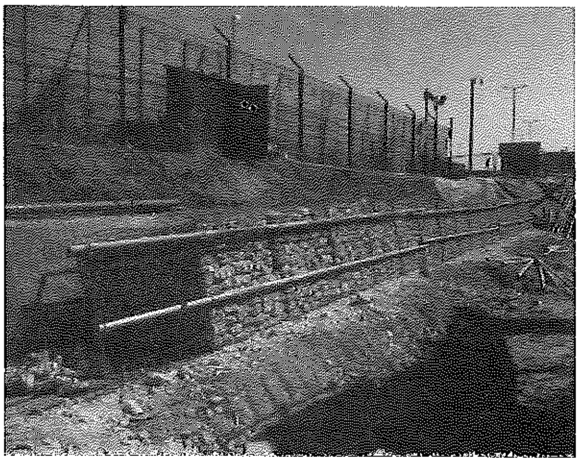


Fig. 33: Filling Pattern of Gabion Boxes

12) MS pipe/frame formwork shall be provided at the gabion facia for achieving a good aesthetic appearance and keeping the bulges within the specified tolerances. The formwork enables to achieve uniformity in the gabion box dimensions during the filling and placement of stones. As far as possible a fair face of large flat stone should be placed at the exposed faces only.



a) Temporary Formwork



b) Use of pipes

Fig. 34: Use of steel frame or pipes to avoid gabion bulging during filling operation

13) The lids are folded back and laced first to the front panels, then to the side ones and to any existing diaphragm to close the Gabions. The gabions in upper layer shall be connected to the top of gabions in the lower layer along the front and back edges of the contact surface using the same connecting procedure. Facia of adjoining units must be securely joined together, along the vertical facing and top edges of their contact surfaces.

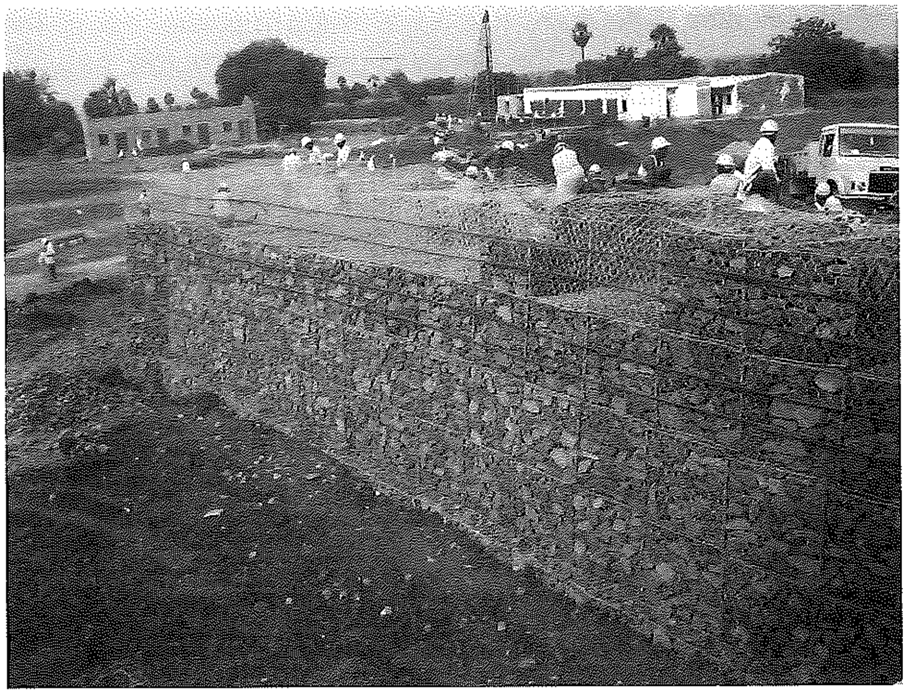


Fig. 35: Lid closing Procedure at Site

14) Other boxes are also placed and packed in position following the same procedure to complete the wall.
15) The Gabions should be covered on the inner face with a non-woven geotextile before placing and compacting the backfill.

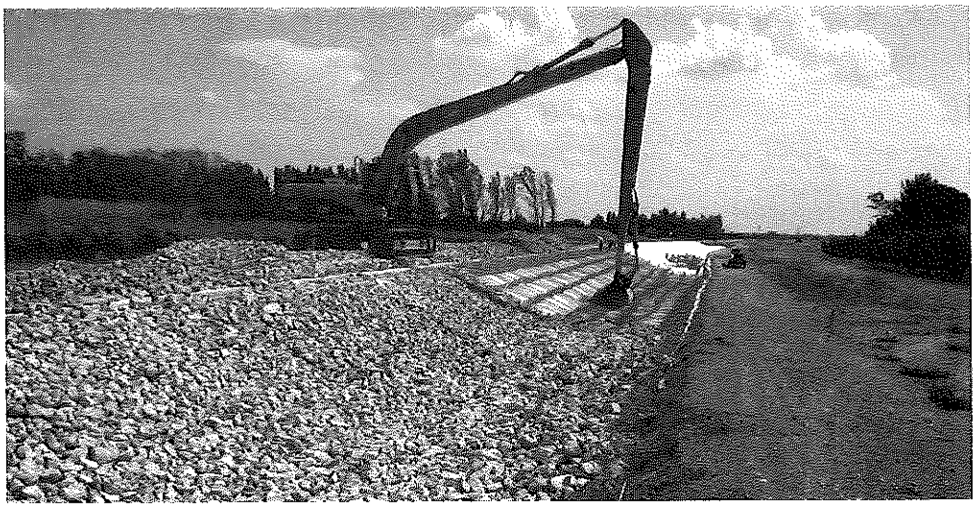


Fig. 36: Typical Photo of Non-woven Geo textile below Revet Mattress during Construction

16) The soil for structural fill shall be placed and compacted to 95% of modified Proctor density in the area behind the gabion units.
17) Compact the structural fill using Vibro-roller of 8 to 10 tonnes capacity. Compacted density shall not be less than 95% modified Proctor density for

the formation. The compaction within 1.5 m of the rear of the face element shall be carried out using vibratory plate compactors or walk behind rollers having 1 tonne capacity.

8.1 Some Causes of Failure of Gabion Retaining Walls

As explained earlier that the Gabion structure is flexible and permeable. While the settlements cannot be avoided, the gabions can adjust to the settled/deformed profile. Development of pore pressure at the back of the wall may be negligible.

There have been some causes of failure of the gabion walls due to improper wrong data, improper design, poor workmanship at site and/or material failure. Some of such failures include:

1) Insufficient data collection required to improper design and hence the final performance is affected.
2) While these structures can be constructed with local labours including skilled and unskilled labour, minimum machinery and equipment, construction of Gabion wall is highly quality conscious. It needs to be constructed as monolithic structure with simultaneous backfilling and compaction which is often not followed at site due to poor workmanship.
3) Improper galvanisation of the wires (mesh, fastening, lacing, stiffening etc.). Improper galvanising leads to the premature degradation of wires/gabions, causing the failure of the structure.
4) Improper foundation and placing of gabion layers without the required preparation can lead to excessive settlements and thereby deformation of the structure.
5) Use of improper graded aggregate or rock and improper filling may lead to post construction deformations of the boxes and settlements.

8.2 Under Water Installation Sequence for Gabion / Revet Mattress

For river bank or flood protection works, it is required to install Gabion/revet Mattress under water. The installation could be either in the river bed or at locations where presence of water cannot be avoided. Method statement for installation of Gabion/revet Mattress underwater presented in following paragraph. There could be changes to this procedure as per site conditions and machinery availability.

The units shall be filled near the site and then placed in position by means of a crane. Great care shall be taken while handling and placing the Mattress or Gabion units to avoid any significant damage. Such units shall be laid close to each other and wired together, if necessary, with wire having the same characteristics of the mesh. For lining steep slopes with revet Mattresses, it is advisable to anchor them at the top of the slope with the help of short piles. This will prevent the sliding of the individual units during placement.

The following sequence shall be adopted for successful placement of the units at the required locations i.e. under or above water.

1) Keep ready the Gabion/ Revet Mattresses for installation. After the filling and placement of stones is completed 16 or 20 mm diameter steel bars are placed along the top perimeter of the unit. These are used for enabling the large-sized hooks of the crane to lift the units without damaging the mesh wire. The diameter of the bar can be finalized depending on the size of the unit.
2) A Barge mounted crane is required in lifting and placing the Revert Mattress or Gabion units at the specified location.
3) The c/c distance between the individual lifting points of the frame shall not be greater than 1m.
4) The Barge is then maneuvered and positioned in such a way that the crane is able to lift and place the revet mattress or Gabion at the specified location.
5) As the revet Mattress is lowered in the water, around 2 - 3 deep water divers take their position around the mattress and guide the crane operator. The divers shall guide the crane operator about the positioning and lowering of frame so that the mattress is placed at approximate location.

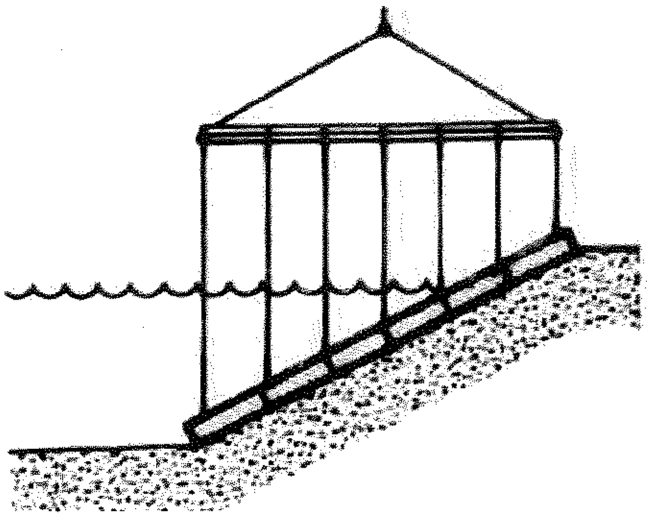


Fig. 37: Underwater Placement of Revet Mattress by Crane

6) Once the Mattress has been placed at the specified location the divers shall signal to the crane operator to halt all movements and lower the boom just a little so that the hooks of the frame can be released under water.

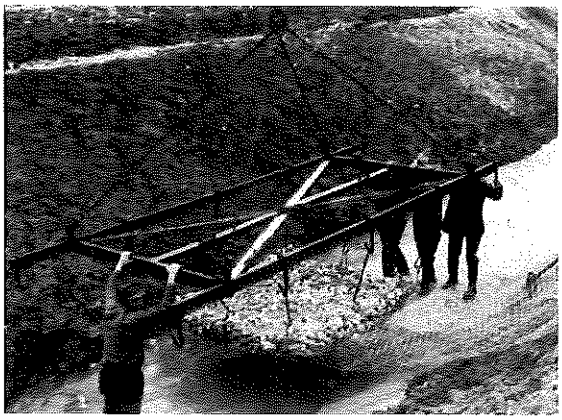


Fig. 38: Underwater placement of Revet Mattress by Crane

8.3 Method of Lifting and Placement of Revet Mattress or Pre-filled Gabions

- Cranes are used to place prefilled gabions on sites where normal methods of assembly and erection would be impractical. For underwater applications, the crane may be mounted on raft or suitable craft if no land access is available.
- The prefilled gabions are lifted by lifting rig which enables the load. The lifting rig is made up of high tensile steel hooks.

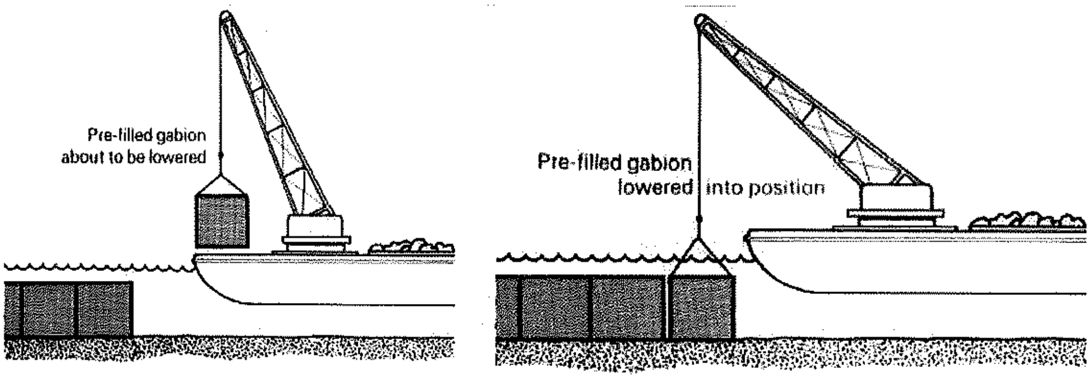


Fig. 39: Underwater Placement of Prefilled Gabions by Crane

8.4 Check List of Site Preparation

Preparation of Site

- The alignment of the structure shall be marked before excavation.
- The excavation shall be carried out as per levels in drawing.
- Excavated area shall be compacted using roller.
- In areas where vibro roller cannot reach, a plate compactor / vibro tamper should be used.
- Weak pockets shall be checked and must be replaced with compacted granular fill.

- The density of formation shall be checked.
- The density of compacted ground shall be more than 95% modified Proctor density.
- The levels shall be checked for confirmation before placement of the gabion / mattress.

8.5 Check List for Installation of Gabion

8.5.1 *Assembly of Gabion units*

- All the Gabion units received at site shall be collapsed and packed in bundles.
- Check for damage to the DT wire mesh of gabion / mattress after opening.
- The unit shall be stretched for removal of fold / bend after opening as per manufacturer procedure.
- The edge wire shall be straightened with wooden mallet.
- The right angle bend shall be formed at all four corners during preparation of the box.
- All vertical panels of the gabion / mattress shall be at one level before the start of lacing.
- All the corners shall be formed by single loop double loop lacing pattern or rings.
- All diaphragms shall be at correct position.
- The dimensions of the units shall be checked.

8.5.2 *Placement of Gabion units*

- Gabion / mattress units shall be placed as per the required alignment of facia
- All adjacent gabion / mattress units shall be connected to each other by the lacing procedure.

8.5.3 *Placement of rock in Gabion box*

- Size and quality of the rocks shall be as per the specifications mentioned in the drawing.
- Temporary formwork shall be used for gabion.
- Check damage of gabion / mattress while placing the rock fill.
- Rockfill in Gabion / mattress shall be filled in layers not exceeding 300 mm.
- Porosity of gabions shall be in between 30% to 40%.
- The internal cross-ties / tie wires shall be provided after every 300 mm of rock fill.
- The lid of the unit shall be matched as per the required alignment of facia.
- Levels shall be taken at every 10m along of wall length.

9 REFERENCES

A. National Guidelines and codes

1. IS 14458(Part 1)-1998 "Retaining wall for hill area - Guidelines: Part 1 Selection of type of wall".
2. IS 14458(Part 2)-1997"Retaining wall for hill area - Guidelines: Part 2 Design of retaining/breast walls".
3. IS 1893(Part 1)-2016 "Criteria for Earthquake Resistant Design of Structures - Part 1 : General provisions and Buildings"
4. IS 16014-2012 "Mechanically woven, double-twisted hexagonal wire mesh gabions, revet mattresses and rockfall netting-specification".
5. IS-2720_Part 4-1985 "Method of test for soils-Part 4-Grain-Size-Analysis".
6. IS 1498-1970 "Classification and identification of soils for general Engineering purposes (first revision)".
7. IRC-6- 2017 "Standard specifications and Code of Practice for Road Bridges- Section-II-Loads and Load combination(Seventh Revision)"
8. IRC-78-2014 "Standard specifications and Code of Practice for Road Bridges- Section-VII-Foundations and Sub-structure".
9. IRC-SP-102-2014 "Guidelines for design and construction of reinforced soil walls"

B. International Guidelines and codes

10. BS: 8002-1994 "Code of practice for Earth retaining structures".
11. BS 8006-1-2010 "Code of Practice for strengthened/Reinforced Soils and Other fills".
12. FHWA-NHI-00-043-2001 "Mechanically Stabilized Earth Walls and Reinforced Soil Slopes - Design and Construction Guidelines ".
13. Annexure B1-HEC 11-FHWA-IP-89-016-1989 "Design of Riprap revetment"
14. Annexure B2-HEC-23-FHWA-NHI-09-112-2009 "Bridge scour and stream instability countermeasures: Experience, selection and design guidance-third edition".
15. EN 10244-Part 1-2000 "Steel wire and wire products-Non –ferrous coating on steel wire"
16. EN 10244-Part 2-2000 "Steel wire and wire products-Non –ferrous coating on steel wire"
17. EN 10223-3:2013 "Steel wire and wire products for fencing and netting-Part 3:Hexagonal steel wire mesh products for civil engineering".
18. AASHTO M288 : 2011 "Standard Specification for Geotextiles Specification for Highway Applications"

C. Other Publications

19. CWC report -2012 "Handbook for flood protection, Anti Erosion and River training works".
20. Simons, D.B., Chen, Y.H., and Swenson, L.J., 1984, "Hydraulic Test to Develop Design Criteria for the Use of Reno Mattresses." Report prepared for Maccaferri Steel Wire Products, LTD. Ontario, Canada, Civil Engineering Department, Colorado State University, Fort Collins"
21. GRI Standard Practice GG-4(b) "Determination of the Long-Term Design Strength of Flexible Geogrids"
22. S.S.Momin, P.L.Khatu and A.D. Gharpure India Highways, Volume 31,No 6 "Eco-Compatible Gabion Retaining Walls on Hilly section of Mumbai-Pune Expressway"
23. Agostini,R.,Cesario,L.,Conte A.,Masetti,M.,Papetti,A.," Flexible Gabion structures in Earth Retaining Works", Officine Maccaferri S.P.A Publication Bologna-Italy.
24. Agostini,R.,Cesario,L.,Conte A.,Masetti,M.,Papetti,A.," Flexible Gabion structures and Reno mattress structures in river and stream training works" -Section 2-Longitudinal works", Officine Maccaferri S.P.A Publication Bologna-Italy.

Annexure I

Item Description of DT Products

Product	Item description	Unit of Measurement	Quantity	Rate
Gabion Boxes of height 1m	Supply of Mechanically Woven Double Twisted Hexagonal Shaped Wire Mesh 1m High Gabion Boxes as per IS 16014, MORTH 2013 specification Clause 2500, of required sizes, Mesh Type --, (Zn(..%)+Al (.. %)alloy)+ Polymer (PVC) coated , Mesh Wire dia. --- (ID/OD), mechanically edged/selvedged, with partitions at every 1m interval and tying with lacing wire of dia -- mm (ID/OD), supplied @ 3% by weight of gabion boxes (excluding transportation) ,as per detailed specification conforming to codes in vogue all complete as per directions of engineer-in-charge.	cum		
Gabion Boxes of height 0.5 m	Supply of Mechanically Woven Double Twisted Hexagonal Shaped Wire Mesh 0.5m High Gabion Boxes as per IS 16014, MORTH 2013 specification Clause 2500, of required sizes, Mesh Type --, (Zn(..%)+Al (..%) alloy)+ + Polymer (PVC) coated, Mesh Wire dia. --- (ID/OD), mechanically edged / selvedged, with partitions at every 1m interval and tying with lacing wire of dia -- mm (ID/OD), supplied @ 3% by weight of gabion boxes (excluding transportation), as per detailed specification conforming to codes in vogue all complete as per directions of engineer-in-charge.	cum		

Product	Item description	Unit of Measurement	Quantity	Rate
Revet Mattress of thickness 0.17m	Supply of Mechanically Woven Double Twisted Hexagonal Shaped Wire Mesh 0.17m thick revet Mattress (excluding transportation), as per IS 16014, MORTH 2013 specification Clause 2500, of required sizes, Mesh Type --, (Zn(..%)+Al(..%) alloy)+ + Polymer (PVC) coated, Mesh Wire dia. -- (ID/OD), mechanically edged / selvedged, with partitions at every 1m interval, tying with lacing wire of dia -- mm (ID/OD), supplied @ 3% by weight of gabion boxes ,as per detailed specification conforming to codes in vogue all complete as per directions of engineer-in-charge	sqm of mattress plan area		
Revet Mattress of thickness 0.23m	Supply of Mechanically Woven Double Twisted Hexagonal Shaped Wire Mesh 0.23m thick revet Mattress (excluding transportation), as per IS 16014, MORTH 2013 specification Clause 2500, of required sizes, Mesh Type --, (Zn(..%) +Al (.. %)alloy)+ Polymer (PVC) coated, Mesh Wire dia. ---mm (ID/OD), mechanically edged / selvedged, with partitions at every 1m interval, tying with lacing wire of dia -- mm (ID/OD), supplied @ 3% by weight of gabion boxes ,as per detailed specification conforming to codes in vogue all complete as per directions of engineer-in-charge	sqm of mattress plan area		
Revet Mattress of thickness 0.3m	Supply of Mechanically Woven Double Twisted Hexagonal Shaped Wire Mesh 0.30m thick revet Mattress (excluding transportation), as per IS 16014, MORTH 2013 specification Clause 2500, of required sizes, Mesh Type --, (Zn(..%)+Al(..%) alloy)+ Polymer (PVC) coated, Mesh Wire dia. --mm (ID/OD), mechanically edged / selvedged, with partitions at every 1m interval, tying with lacing wire of dia -- mm (ID/OD), supplied @ 3% by weight of gabion boxes ,as per detailed specification conforming to codes in vogue all complete as per directions of engineer-in-charge	sqm of mattress plan area		

Product	Item description	Unit of Measurement	Quantity	Rate
Filter layer	Supply and laying of non-woven geotextile, having a grab tensile strength in N, trapezoidal tear strength in kN/m, puncture strength in N with maximum apparent opening size in mm, permittivity in per sec provided in roll of length in metre and width in metre	sqm		
Rock filled in Gabion/revet mattress	Stone for the Gabion/revet mattress facia shall be hard, angular to round, durable and of such quality that they shall not disintegrate on exposure to water or weathering during the life of the structure. The stone size shall range between 1.5 to 2.5 times mesh opening. Each range of sizes may allow for a variation of 5% oversize or 5% undersize, or both. The size of any oversize stone shall allow for the placement of minimum of three layers of stone must be achieved when filling the 1 m high units and a minimum of two layers for the 0.50 m high units. The stone used for filling the gabion facia shall have a minimum density of 22kN/m3 and Los Angeles abrasion value not more than 45.	cum		

Example: Gabion Boxes Zn Al alloy polymeric coated of height 1m

Supply of Mechanically Woven Double Twisted Hexagonal Shaped Wire Mesh 1m High Gabion Boxes as per IS 16014, MORTH 2013 specification Clause 2500, of required sizes, Mesh Type 10x12, Zn90%/Al10%, Polymer (PVC) coated, Mesh Wire dia. 2.7/3.7 mm (ID/OD), mechanically edged / selvedged, with partitions at every 1m interval and tying with lacing wire of dia 2.2 / 3.2 mm (ID/OD), supplied @ 3% by weight of gabion boxes (excluding transportation) ,as per detailed specification conforming to codes in vogue all complete as per directions of engineer-in-charge.

Annexure II
(clause 7.2)

Details of Thickness of Gabion Mattress in Relation to Water Velocity

Research and Development work carried out at Colorado State University Fort Collinsto test the performance of gabion mattress under various hydraulic conditions. This test was carried out both at full-scale and on scale-model to establish the behaviour and stability of channel revetment protected with Gabions and mattress. Based on the research results, the thickness of the mattress is selected considering the flow velocity that the mattress has to sustain and the average stone fill size that would be available for filling the mattress box. This selected thickness of mattress is then checked for the tractive shear stress criteria i.e. the revetment stability check along the bed and slope portion.

Table II-1 Indicative Thickness of Gabion Mattress in Relation to Water Velocity [20]

Type	Thickness (m)	Stone size (m)	d_{50} (m)	Critical Velocity (m/s)	Limiting Velocity (m/s)
Revet mattress	0.15-0.17	0.07-0.10	0.085	3.5	4.2
		0.07-0.15	0.11	4.2	4.5
	0.23-0.25	0.07-0.10	0.085	3.6	5.5
		0.07-0.15	0.12	4.5	6.1
	0.3	0.07-0.12	0.1	4.2	5.5
		0.10-0.15	0.125	5.0	6.4
Gabion	0.5	0.10-0.20	0.15	5.8	7.6
		0.12-0.25	0.19	6.4	8.0

Table II-2: Indicative Gabion Mattress Thickness [13]

Bank soil type	Max velocity(m/s)	Bank slope	Minimum thickness required(m)
Clay, Heavy cohesive soil	3.05	<1:3	0.23
	3.96-4.88	<1:2	0.3
	any	>1:2	≥.45
Silts, Fine sand	3.05	<1:2	0.3
Shingle with gravel	4.88	<1:3	0.23
	6.01	<1:2	0.3
	any	>1:2	≥0.45

Where, Critical Velocity- the maximum velocity at which no movement of the filling material will occur. Limit Velocity denote the velocity at which modest deformation of the mattress has occurred due to movement of the fill material and which does not materially affect the discharge capacity.The thickness of the mattress is determined by three factors: the erodibility of the bank soil, the maximum velocity of the water, and the bank slope. When precise soil investigation is not available, preliminary thickness of mattresses can be chosen from **Table II-2**. These values are based on observations of a large number of mattress installations which assume a filling material.